NAVAL POSTGRADUATE SCHOOL
Monterey, California

COMPARISON OF BRADLEY M2A2 AND M2A3 USING JANUS

by

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September 1996

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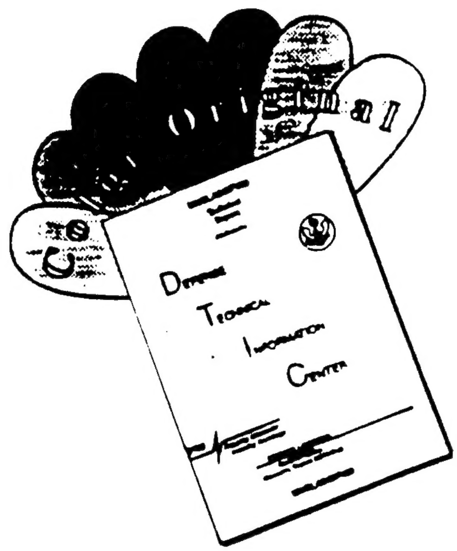

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1996	Master's Thesis

4. TITLE AND SUBTITLE
COMPARISON OF BRADLEY M2A2 AND M2A3 USING JANUS

5. FUNDING NUMBERS

6. AUTHOR(S)
Steven Andrew Lovaszy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

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The purpose of this thesis is to compare the two variants of vehicle in the Pre-test Modeling phase of the Model-Test-Model concept. This thesis used the Janus high resolution combat model, to simulate the vehicles and weapon systems under two scenarios, a Head-to-Head scenario, and a Force-on-Force scenario. The Head-to-Head scenario is a simulation of the future Limited User Test 2 to be conducted by TEXCOM. The Force-on-Force scenario is a simulated battle between a Bradley platoon and a Soviet style tank heavy company.

Data was gathered from the Janus created postprocessor files of the two scenarios. The analysis compared four measures of effectiveness (MOEs), in the areas of detection, engagement, lethality, and survivability. The aim of the analysis was to detect differences between the vehicle variants using the two sample T-test and the Mann-Whitney-Wilcoxen test.

14. SUBJECT TERMS
Bradley Fighting Vehicle, M2A3, Janus

15. NUMBER OF PAGES
99

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

Approved for public release; distribution is unlimited

COMPARISON OF BRADLEY M2A2 AND M2A3 USING JANUS

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Submitted in partial fulfillment of the
requirements for the dual degrees of

MASTER OF SCIENCE IN OPERATIONS RESEARCH
and
MASTER OF SCIENCE IN APPLIED MATHEMATICS
from the

NAVAL POSTGRADUATE SCHOOL
September 1996

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EXECUTIVE SUMMARY

The Bradley Fighting Vehicle System M2A3 (BFVS-A3) is currently under development by the US Army. The vehicle is based on the M2A2 variant, presently used by mechanized infantry units, with modifications introduced as a result of Operation Desert Storm and new technologies. This thesis used the Janus high resolution combat model, version 6.0, to provide a comparison between the BFVS-A2 and BFVS-A3. The thesis forms part of the Pretest Modeling phase of the Model-Test-Model concept. The aims of the thesis were:

1. To develop Janus scenarios which model the Limited User Test 2 (LUT 2), to be conducted by TEXCOM;
2. To examine the performance of both vehicles in a scenario against a Soviet style tank heavy company attack;
3. To compare the two vehicles using measures of effectiveness developed from the critical issues of detection, engagement, lethality, and survivability.

In achieving these aims, both vehicle's characteristics were researched to produce the Janus model systems. In addition, the tactics used by the Bradleys were studied to produce accurate scenarios from which data could be gathered to conduct the comparison. A Head-to-Head scenario was developed to model the LUT 2. It featured a platoon of Bradley vehicles in hasty defense and a platoon of Bradleys attacking. The roles of defender and attacker were replicated with both vehicle variants to provide the data to compare the ability to detect for each vehicle. A Force-on-Force scenario was developed involving a Bradley platoon in a deliberate defensive position with a Soviet style tank heavy company attacking. It was used to compare the maximum engagement range, the number of kills achieved, and the number of shots withstood by the Bradleys.

The results of two statistical tests were used to show that the BFVS-A3 outperformed the BFVS-A2 in detection, lethality, and survivability and that the vehicles were not different in maximum engagement range. However the magnitude of the

differences was not considered great enough to provide a tactical advantage to the Bradley A3 platoon.

The research involved in gathering unclassified data on which to base the Janus models suggested that different results would probably be produced by using the classified data not used in this thesis. This type of pretest modeling and analysis should be conducted again with the classified data before the results of the comparison between vehicles could be considered accurate.

I. INTRODUCTION

The Bradley Fighting Vehicle has been in use with the US Army since 1980. It is a fully tracked, medium armored fighting vehicle which provides protected, superior cross country mobility and vehicular mounted firepower to Infantry and Cavalry units. The first two variants were designated the M2 if used by Infantry units and the M3 if used by Cavalry units. The M2 and M3 are basically the same vehicle except that the M3 only carries five personnel, three crew and two scouts, and therefore can carry more ammunition than the M2 which carries a crew of three and a six man squad ready to dismount. By 1987 provisions to launch the TOW 2 missile were included on the Bradley vehicle. With these improvements, the vehicles were designated the M2A1 and M3A1. The later M2A2 and M3A2 versions are still currently used by the Mechanized Infantry and Cavalry units respectively. These vehicles have higher survivability through the addition of advanced appliqué armor tiles, internal spall liners and restowage of ammunition to minimize battlefield damage. [Ref. 1:p. 1113] In addition, both vehicles have a later model, 600 horsepower powertrain package. During Operation Desert Storm, there were approximately 2200 Bradley Fighting Vehicles (BFVs) employed in the Kuwait theater of operations. The Bradleys were praised by the Army for their performance, however this combat experience has lead to the requirement for further modifications to the vehicle.

The need has been identified to upgrade the Bradley Fighting Vehicle System (BFVS) to facilitate enhanced command and control, lethality, survivability, mobility and sustainability required to defeat current and future threat forces while remaining operationally compatible with the BFV M2A2 and the M1 main battle tank (MBT).[Ref. 2:p. 1] The BFVS-A3 is currently in the early stages of the acquisition program. The required upgrades have been identified and the first stage testing, the Limited User Test 1 (LUT 1) has been conducted with two prototype vehicles. This test examined the ability of the BFVS-A3 vehicles as a section to effectively maneuver, detect and engage targets in a variety of operational conditions. [Ref. 2:p. 39]

The test was conducted in December 1994 at Fort Hunter Liggett, CA by the Close Combat Test Directorate of the Test and Experimentation Command (TEXCOM). The test was conducted to determine the impacts of the proposed improvements in three areas: (1) vehicle combat effectiveness and mobility; (2) collection of test data for validating the integration of the Operation Desert Storm (ODS) improvements; and (3) determining the compatibility of current systems and the ODS improvement systems with respect to each other while all systems are fully operating.

During October - November 1997 the Army will conduct the LUT 2 for the BFVS-A3. The LUT 2 will involve the field testing of preproduction vehicles, in operational scenarios, to examine the critical issues identified for the Operational Test and Evaluation (OTE) process. These issues are outlined in the Test and Evaluation Master Plan (TEMP). [Ref. 2:p. 2] As the OTE is a very expensive process, there is a great deal of interest in ensuring that the field testing conducted will effectively address the critical issues of concern. A test that does not give the opportunity to use the improvements to demonstrate the vehicle's superiority is useless. In addition, where a test involves a number of limited resources such as time, troops, vehicles etc. to assess the critical issues, it becomes increasingly important to have a well designed field test.

A process called Model - Test - Model (MTM) is currently used to bring the benefits of simulation into the acquisition process. The details of the MTM process will be discussed in the next section. At this stage, consider the process to involve the modeling of a new system or a modified system, followed by field testing, followed again by modeling to predict the operational performance of the system. This thesis will use the Janus, high resolution combat model, version 6.0, in the Pretest Modeling Phase of the MTM process. It will model the LUT 2 and an enemy threat scenario to provide a comparison of the BFVS-A3 to the BFVS-A2. A number of Measures of Effectiveness (MOEs) will be identified with which to make the comparison using the output from the Janus simulation. A comparison is made between the two vehicles with regard to the vehicle's ability to detect and engage armored vehicles and its survivability and lethality. In addition, the development of the Janus scenarios will provide valuable insight into the

conduct of the live field test, potentially conserving the limited resources of the LUT 2, particularly time and money.

A. MODEL-TEST-MODEL (MTM) PROCESS

The purpose of this section is to describe the MTM process and the part to be played by the use of a high resolution combat model such as Janus. The MTM process consists of five phases as shown in Figure 1. These phases are Long Term Planning; Pretest Modeling; Field Test; Post Test Modeling; and Accreditation. [Ref. 3:pp. 3-6] This thesis forms part of the Pretest Modeling phase. The MTM process is an approved Operations Research technique that has become part of the Test and Evaluation Policy for the Army [Ref. 3:p. 1].

MODEL - TEST - MODEL PHASES	
I	Long Term Planning
II	Pretest Modeling
III	Field Test
IV	Post-Test Modeling and Calibration
V	Model Accreditation (or Validation)

Figure 1. Phases of M-T-M Concept

As this thesis focuses on the Pretest Modeling phase, this phase will be explained further after a brief description of the other phases. The Long Term Planning phase consists of identifying the responsibilities of the organizations involved in the acquisition program. The Field Test phase is characterized by the collection of authentic test data under replicated operational scenarios with the aim of quantitatively showing the ability of the new system. It is also used to provide a comparison between new and old systems or a comparison between a number of alternative new systems. It is preferable that the

modeler of the Pretest phase becomes involved in the Field Test phase to be familiar with the conduct and data collection of the test. The modeler may see differences between the actual test and the assumptions made during Pretest modeling which affect the model's ability to predict results. During the fourth phase, Post Test Modeling, the parameters of the model are able to be refined to match the results of the field test. The model should then as closely as possible match the real system. Running the model again in the test scenarios should now produce similar results as the field test, particularly in the critical areas modeled such as detections, engagements and movement. The advantage of this process now becomes evident. The simulation may be run as many times as desired at little cost compared to further conduct of the field test. The simulation results then provide statistical confidence to the Measures of Performance (MOPs) or Measures of Effectiveness (MOEs) of concern. The final phase is Model Accreditation. In this phase, the model must be shown to replicate the field test with sufficient evidence that the tester of the system has confidence in the model and the results that it shall produce under a number of different operational scenarios. This phase involves the validation of the model results to the field data.

The second phase and the area of particular relevance to this thesis is the Pretest Modeling. Pretest Modeling involves two tasks, the first is to observe the new system, determine a suitable method to conduct the test, and the best tactics to be used in the scenario of the actual field test. Secondly, the modeler is able to predict the ability of the test scenarios to capture the data required, which illustrates the objectives that have been set for the test. In this way the test scenarios may be refined to ensure that useful data will be produced to address the critical issues, prior to the conduct of the expensive, time consuming field tests which may otherwise have been wasted. The critical issues for the system have been identified in the Planning phase are usually stated explicitly in the Test and Evaluation documentation. The use of a high resolution combat model, like Janus, will provide the ability to look at many alternative locations and ways to conduct the test to ensure that the critical issues will be brought out during the test. For example, if a new system has greater range capability and engagement at maximum range has been identified

as a critical issue, then the test must allow the opportunity for detection at ranges in excess of the old system's engagement range. If not, the two systems will engage at the same close range and no resulting improvement by the new system will be displayed. Adjustments to the scenario can then be made based upon model results prior to actual field testing.

By involving the participants of the field test in the Pretest Modeling, the simulation can provide a "what if" tool to determine courses of action should those conditions arise in the field test. This is particularly relevant to tests involving maneuver forces where so often actions depend on the information available to the commander at the time and decisions are made quickly. In this way, the courses of action may be reviewed to accurately represent doctrine and the situation intended by the test developers. The test must still remain unscripted to depict the operational setting and decision making. However, the conduct of a successful test is more likely, in the same way that rehearsal of the maneuver or firing doctrine would assist, but without the same cost. The Pretest Modeling phase requires a two way flow of information between the developers of the field test and the developers of the model. This assists in producing the best test scenario, with the players prepared to conduct the test in the way it is intended. In addition, the model produced best reflects the system prior to the test being conducted and prior to the test results being used to refine the model.

B. BRADLEY FIGHTING VEHICLE M2A2

The Bradley Fighting Vehicle (BFV) arose from a need to extend the capabilities of the M113 Armored Personnel Carrier (APC). The M113 APC provided a lightly protected method of transporting troops around the battlefield. It was not, however, a vehicle from which the Infantry soldiers being carried could fight or view the battlefield. In addition there was a need for the armament of the vehicle to be able to defeat enemy light armor. The Soviet Army was aware of this need and developed the BMP series of

vehicles to accompany and later replace the BTR series of vehicles which were APCs, as opposed to Infantry Fighting Vehicles (IFV).

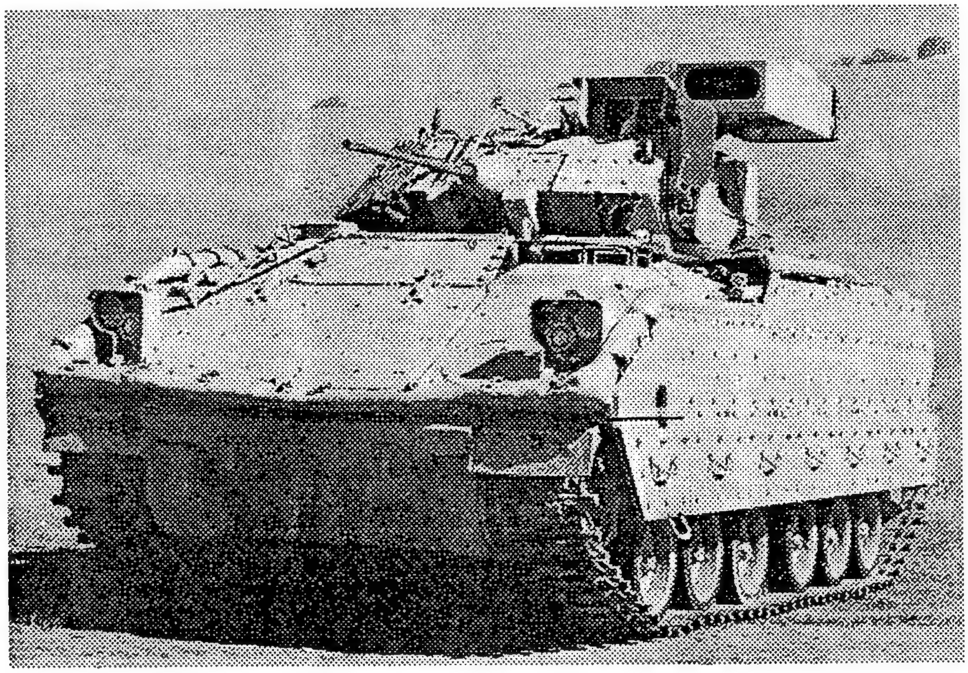


Figure 2. The M2A2 Bradley Fighting Vehicle
Photo taken from Ref. 4.

By April 1991, 5471 Bradley vehicles had been built, 3400 were M2 vehicles for Mechanized Infantry units, similar to the one shown in Figure 2, and 2071 were M3 vehicles for Cavalry units. [Ref. 4:p. 53] Of the 2200 Bradleys in the Middle East theater of operations, only three were disabled and operational readiness rates remained at 90 per cent or above during combat [Ref. 5:p. 382].

1. Vehicle Characteristics

The hull of the Bradley is made of all-welded aluminum armor with spaced laminated armor fitted to sides and rear. The M2A2 vehicles have an additional layer of appliqué steel armor plus provisions for explosive reactive or passive armor for increased survivability. The turret is composed of welded steel and aluminum armor with a main armament 25mm Chain Gun and a coaxially mounted 7.62 mm machine gun. The turret

holds two 4 tube electrically fired smoke grenade launchers, one on each side of the 25mm gun. Each launcher fires four grenades simultaneously which together create enough smoke to screen the vehicle in three seconds. The A1 modifications included a NBC gas particulate filter system and a revised fuel system for increased survivability. The A2 variant enhanced survivability through restowage of ammunition, internal armor protection for key components, spall liners, additional armor protection and an improved drive train. All of the earlier vehicle variants have been retrofitted with these A2 upgrades. The vehicle crew consists of the Commander, Gunner and the Driver. Within the Mechanized Infantry role, a squad of six personnel is carried in the back of the vehicle and can dismount along with the Commander when required.

2. Weapon Characteristics

The main armament is a M242 25mm automatic gun. It can fire a variety of ammunition types including armor piecing discarding sabot (APDS) and high explosive (HE) rounds. The APDS round will defeat light armor vehicles, self propelled artillery and helicopters to a range of 2000 meters. The HE round is used to destroy unarmored vehicles and helicopters and to suppress crew served weapons and dismounted infantry to 3000 meters. The M240C 7.62mm coaxial machine gun is used to engage dismounted infantry and crew served weapons to a range of 900 meters. In addition there is a tube launched, optically tracked, wire guided (TOW) missile system mounted on the turret. The TOW system is a twin tube, anti-tank, guided weapon to enable the engagement of enemy armor to a range of 3750 meters. The launcher holds two rounds and there are an additional five rounds carried in the vehicle. The vehicle crew can reload the launcher without being exposed to hostile fire.

C. BRADLEY FIGHTING VEHICLE M2A3

As a result of Operation Desert Storm, a number of improvements have been integrated into some BFVs. These include a laser range finder, Global Positioning System with compass, a simple Identification Friend/Foe (IFF) capability, a driver's thermal viewer and a missile countermeasure device. The resultant vehicle is called the M2A2/ODS (Operation Desert Storm). These modifications have been made to a number of vehicles and are now incorporated into the Bradley M2A3 / M3A3 program. The program covers the following six key areas :

a. Core electronic architecture - 1553 databus, central processors and memory, digital information displays for commander, driver and squad leader;

b. Lethality - improved acquisition, ballistic fire-control solution, automatic dual target tracking, automatic gun target adjustment, automatic boresighting, and a hunter / killer capability.

c. Survivability - combat identification system, roof fragmentation protection, squad ventilated facepiece and armor tiles;

d. Independent thermal viewer;

e. Sustainability - digital electronics, embedded training, digital built-in test equipment and digital logistics reporting; and

f. Mobility - improved driver's vision.

There are a number of new systems included in the M2A3 which will provide for the improved capabilities. These are :

a. the Driver's All-Weather Viewer (DAWV),

b. the Improved Bradley Acquisition System (IBAS),

c. the Commander's Independent Viewer (CIV),

d. the Bradley Eyesafe Laser Rangefinder (BELRF),

e. the Precision Lightweight Global Positioning System Receiver (PLGR),

f. a flat panel display,

g. fire control software,

h. C2 software, and

i. diagnostic software.

The DAWV is a thermal viewer which allows the vehicle to maneuver at normal daytime driving speeds in darkness, under all weather conditions, and degraded visibility due to smoke and other battlefield obscurants. The viewer also provides a silent surveillance capability and an assistance for target acquisition [Ref. 6:pp. 1-4]. The IBAS provides a Second Generation Forward Looking Infrared (FLIR) sight to the gunner and one to the commander. IBAS is a further development of the TOW Improved Target Acquisition System (ITAS), which is an upgrade to the TOW 2 weapon system. The IBAS is being developed by Texas Instruments and will undergo an integration demonstration in December 1996. The IBAS FLIR will provide an increased range and greater capability for detection than the First Generation FLIR. The CIV provides the commander a stabilized, 360 degree panoramic view of the battlefield. It incorporates the commander's IBAS and a day TV view. The CIV allows the BFVS-A3 to continue to fight when "buttoned-up", providing the crew enhanced survivability. The BELRF allows ranging from 200 to 9990 meters in five meter increments, to an accuracy of plus or minus 10 meters at maximum range. It allows 99 percent probability of detection for standard NATO targets at 6000 meters, given a visibility of 8000 meters with zero precipitation [Ref. 6:pp. 1-3]. The PLGR provides precision position coordinates, time and navigation information under all conditions if there are no obstructions between the satellite signals and the antenna [Ref. 6:pp. 1-3]. The flat panel display will provide the commander and the squad with real time, digital command and control information, tactical graphics and video display from the IBAS, CIV or DAWV.

In addition to the software and sighting systems already detailed, the M2A3 will provide restowage modifications for TOW, Javelin and 25mm ammunition, and a Missile Countermeasure Device (MCD). This system can defeat a variety of currently fielded first and second generation anti-tank, guided missiles. This is accomplished by generating false commands to the incoming missile guidance system. The system's performance is limited by the angle of coverage, battlefield haze and dirt on the system window [Ref. 6:pp. 1-6].

This thesis will model those characteristics described above which can be incorporated into the Janus simulated vehicle and weapon system. The Janus models of the BFVS-A2 and BFVS-A3 can be compared in the two scenarios of interest to TEXCOM. The first is the LUT 2 scenario and the second is the Force-on-Force test scenario. The following chapters will describe these two scenarios, the Janus models and simulation runs, and the analysis used to compare the new and old vehicles.

II. SCENARIO DESCRIPTION

The purpose of this chapter is to describe the LUT 2 scenario, which in this thesis will be referred to as the Head-to-Head test, and the scenario developed for a Force on Force test. It will also define the critical system characteristics of the BFVS-A3 and the critical operational issues as outlined in the TEMP. These aspects will produce a number of issues that will be analyzed later in this thesis. The final section of this chapter will detail the Measures of Effectiveness (MOEs) that have been identified for the comparison of the BFVS-A2 to the BFVS-A3 under the two simulated scenarios. The Head-to-Head test will consist of a platoon of four M2A2 variant vehicles against a platoon of four M2A3 variant vehicles. To keep the costs of the field test down, the BFV platoons will face off against each other in each battle run. Therefore, one variant can be tested for its capabilities from a defensive position at the same time as the other variant is tested in the attack. This test scenario is not the preferred method for this type of comparison because it does not have a realistic enemy threat on which to assess the BFVs or a constant opposing force on which to base the test between the two vehicles. Therefore, TEXCOM is interested also in the results of a simulated scenario of the Bradley platoons against a Soviet style enemy threat. This scenario will be referred to as the Force-on-Force test. This chapter will include the force sizes used in the simulation and a discussion of the tactics used. The LUT 2 is to be conducted at Fort Hood, Texas, therefore all scenarios will be run on this terrain data. The scenarios have been developed from the Janus terrain files available for the training areas at Fort Hood. The scenarios used have been chosen so that they utilize only the training areas known as Landgroup 3, 4 or 5, with each separate battle scenario not crossing the boundary of an individual landgroup. TEXCOM has determined these areas to be suitable to conduct the test. If possible they would prefer to require only one area at a time, to minimize the utilization of the training area. The scenarios of the Head-to-Head test to be conducted in this thesis will therefore only require one landgroup area at a time.

A. HEAD-TO-HEAD TEST

The LUT 2 will be conducted in three phases. The first phase will consist of individual and unit training for five vehicle crews. The second phase will be crew and platoon gunnery tests. The third phase is the maneuver phase consisting of eight head-to-head battles. [Ref. 2:pp. 39-40] Data will be collected during this phase to assess the operational effectiveness and suitability of the M2A3 relative to the M2A2. The test will examine the ability of the vehicles to maneuver, detect, and engage targets under a variety of scenario conditions such as vehicle posture and day or night.

A platoon of M2A3 vehicles will be tested against a platoon of M2A2 vehicles, using the laser based Real Time Casualty Assessment (RTCA) system and the Mobile TEXCOM laser based system (MTEC). The MTEC system will provide a Global Positioning System (GPS) for position location during the test. The battles to be conducted, as outlined in the TEMP are to be an attack by a platoon of BFVS-A3 on a platoon of BFVS-A2 in a hasty defensive position, then again in a deliberate defensive position, conducted both by day and by night. The same conditions will then be rerun with the vehicle types interchanged, i.e. the platoon of BFVS-A2 attacking the platoon of BFVS-A3. Hence there will be eight test battles conducted in total.

This thesis will simulate only a portion of these tests. To keep the number of simulation runs and data collected manageable, only the hasty defense, by day scenarios will be simulated and analyzed in this study.

1. Bradley Platoon

The mechanized platoon of Bradley vehicles consists of two sections of two vehicles, four vehicles total. The vehicles are known as the Platoon Leader's vehicle and his Wingman forming the first section, and the Platoon Sergeant's (PSG's) vehicle and his Wingman in the second section. Although mechanized infantry platoons will normally conduct operations as part of a larger force, they may perform some operations which can

be considered independent. In the first scenario the BFVS-A3 platoon as the lead element of the Advance Guard is conducting a movement to contact. The aim is to gain contact with the enemy and once in contact, to fight for information on the enemy's strengths and weaknesses. The enemy force played by the BFVS-A2 platoon can represent the Combat Reconnaissance Patrol as the lead element of the enemy advance guard.

2. Platoon Formations and Actions

The advancing BFVS-A3 platoon will move in a traveling overwatch formation when not in contact but aware that contact is possible. This formation provides good dispersion and security to the platoon. During traveling overwatch all vehicles of the platoon continue to move in column, wedge, or echelon formation with their turrets oriented to assigned sectors of responsibility. Once contact is expected, the platoon modifies its method of movement to bounding overwatch. Bounding overwatch may be conducted in two ways, alternate or successive bounding overwatch. In open terrain or when speed is important, alternative bounding overwatch is used. When more control is required or the terrain is restrictive then successive bounding overwatch is used. During bounding overwatch, one or two vehicles move to the next bound position while the rest maintain overwatch from a stationary position. The vehicles in overwatch will erect their TOW launchers and self test the weapon as soon as stationary. When moving in alternate bounding overwatch the sections leap-frog to the next bound, thereby taking turns in clearing new ground. When moving in successive bounding overwatch the platoon leader and his wingman will clear to the next bound then the other section will join them before the first section again clears to another bound. Alternate and successive bounding overwatch are shown in Figure 3. Once the platoon has established the enemy strength and effectiveness and its own ability to maneuver, the commander makes the decision to conduct a hasty attack.

During the hasty attack, one section of BFVs provides long range overwatch while the other section maneuvers to conduct the assault. The squads should remain mounted

unless the enemy must be cleared from restrictive terrain or forced to dismount by enemy resistance. In the LUT 2 this scenario will be conducted for the defending force in two different postures, a hasty defense then a deliberate defense. In hasty defense the vehicles will choose positions to fight from based on the available cover from observation and fire. In a deliberate defense the vehicles will have prepared positions behind berms or in dug-in positions which will offer better cover and the positions chosen that offer better fields of view than in the hasty defense layout.

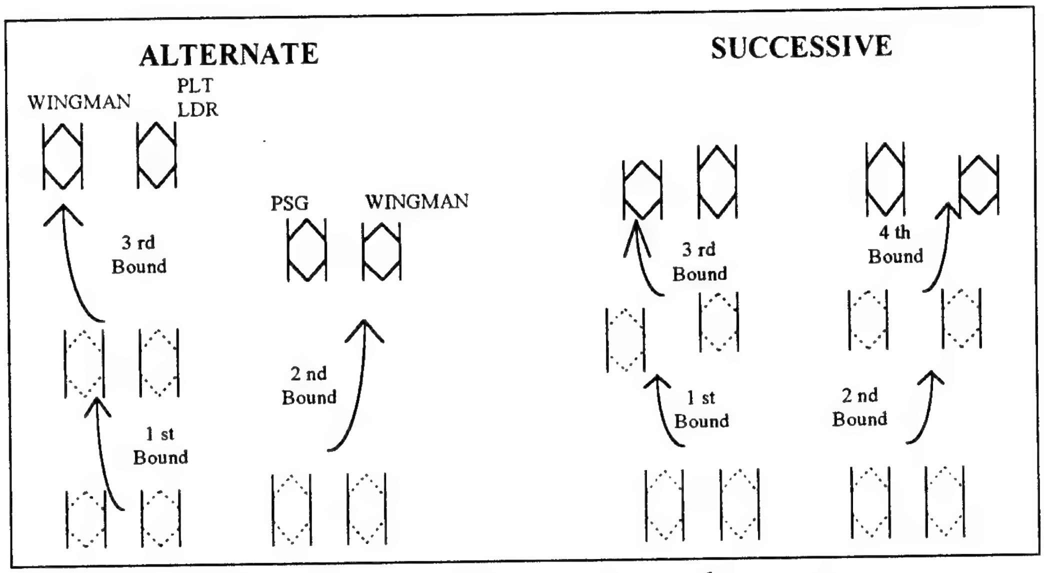


Figure 3. Methods of Bounding Overwatch movement

This thesis simulated the day, hasty defense scenarios of the test. An area of the Fort Hood training area was chosen which allowed the advancing platoon of BFVs to start from a distance beyond maximum visibility and approach an unknown enemy location. The terrain allowed detections to occur commencing from outside maximum weapon range. The advancing platoon then changes formation to use alternate bounding overwatch method of movement to move within weapon range. In this scenario the attacking platoon is expected to lose because there are four vehicles attacking four vehicles which are stationary in positions chosen for good fields of view and fire. The scenario therefore continues with the attacking platoon moving in bounding overwatch

until all attacking vehicles are destroyed. In this way data are produced on which survivability and lethality can be measured.

B. FORCE-ON-FORCE TEST

The Force-on-Force test is comprised of two Janus simulated battles. In the first battle, the friendly force consists of a platoon of BFVS-A2 vehicles and the opposing force was a Soviet style tank heavy Company Team. The second battle was the same scenario with the BFVS-A2 vehicles replaced by BFVS-A3 vehicles.

1. Friendly Force

The friendly force consists of a platoon of BFVs as described in the previous section. The platoon was in a deliberate defensive position, sighted to provide good fields of view and fields of fire in which to employ the TOW system at maximum range possible for this given terrain. In this scenario the Bradley platoon is in a delaying position used to hold the opposing force advance to allow time for preparation of the main defense position. This platoon would employ artillery and air assets to attrit the enemy at maximum range causing maximum delay to the advancing opposing force. These aspects were not used in the simulated scenarios as it is not considered important to the comparison of the two vehicles.

2. Opposing Force

The opposing force consists of a Soviet style, tank heavy Company Team. The Motorized Rifle Company of BMP vehicles is reinforced with a tank platoon from the Tank Battalion from within the Motorized Rifle Regiment. The Motorized Rifle Company is made up of three platoons of three BMP-2 vehicles, a Company Command vehicle and a Machine Gun platoon of two vehicles. [Ref. 7:pp. 4-27] The 12 BMP-2 vehicles each

carry an AT-4, anti-tank guided weapon, and three missiles. The AT-4 fires a high explosive anti-tank (HEAT) round which is effective to a range of 2000 meters. In addition the BMP-2 carries a 30mm automatic gun. The tank platoon consists of four T-72 tanks. The tanks have a main armament 125mm smoothbore gun. The main armament will fire a HEAT round to an effective range of 2100 meters. [Ref. 7:pp. 5-44] The organization of the opposing force is shown in Figure 4.

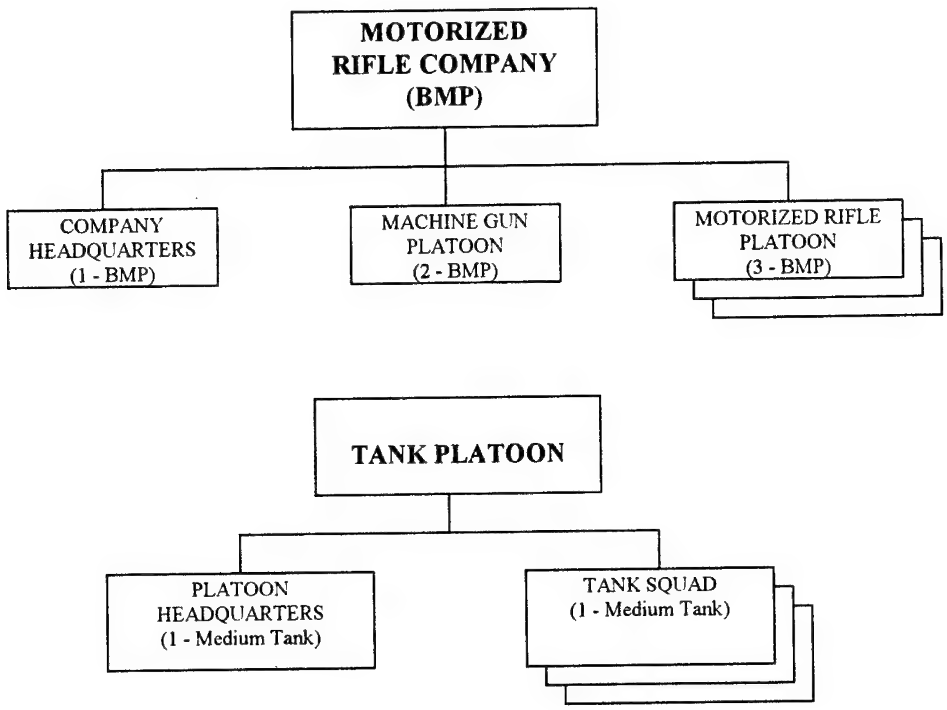


Figure 4. Organization of the Opposing Force

As the Motorized Rifle Regiment of BMP vehicles is advancing, the lead element consisting of a BMP platoon known as the Combat Reconnaissance Patrol, will report the strengths and locations of enemy sightings. The next element is known as the Forward Security Element, it consists of a motorized rifle company reinforced with tanks and artillery, and will be tasked with engaging the lead enemy elements. It is this element that was modeled as the opposing force in the Force-on-Force scenario. The motorized rifle company reinforced with a platoon of tanks conduct an "attack from the march" to

destroy the Bradley platoon in its defensive position. In the prebattle formation, the reinforced company move with the platoons in column being lead by the tanks. Immediately before combat begins the company assumes attack formation. In attack formation the company may move in a line, wedge (one platoon up), or reverse wedge (two platoons up) formation. In the simulation, the tanks lead the BMP vehicles which are using a reverse wedge formation. The attack formation is shown in Figure 5. The Soviets perceive the advantages of the attack from the march to be that the unit is not committed before the attack, the attack increases the chance of surprise, allows greater flexibility, decreases vulnerability to enemy artillery and enhances momentum. [Ref. 8:pp. 5-13]

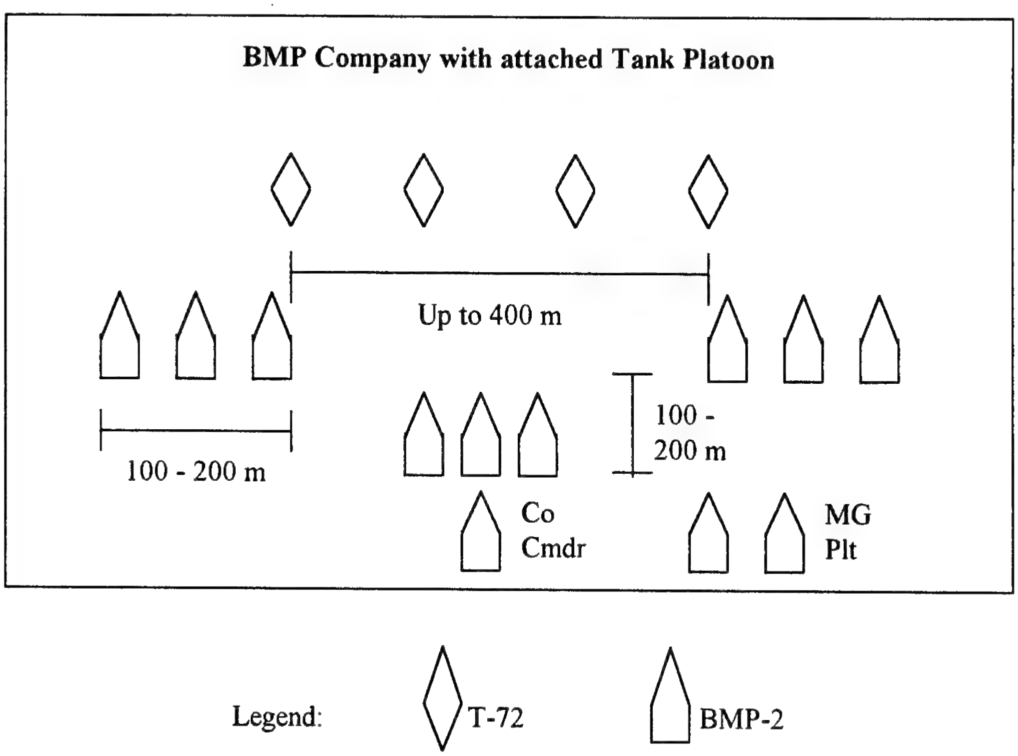


Figure 5. Reverse Wedge Formation (Mounted)

The simulated scenario has the opposing force advancing toward the Bradley position from beyond maximum visibility range. Once the first detection occurs, the

opposing force commences moving in attack formation with the company in a reverse wedge formation of platoons. The first detection may not and will probably not be by the opposing force since the BFV position should be well camouflaged, however, since artillery or some other form of fire would normally be used at this time the opposing force will change formation and be aware of the presence of a position somewhere to their front from this time. This simulation of this scenario continues with the company team attacking the BFV position until all BFVs are destroyed.

C. MEASURES OF EFFECTIVENESS

The issues that are to be used in the comparison between the two vehicle variants are derived from the issues raised in the TEMP as critical to the performance of the new variant. From these issues those aspects that could be modeled reasonably accurately by the Janus simulation are selected as the issues to be analyzed in this thesis. The TEMP outlines eight issues as Critical System Characteristics of the BFVS-A3. [Ref. 2:p. 2] These issues are :

1. Provide a command and control (C^2) system that will meet the requirements as defined by the Battlefield Command and Control System capstone Operational and Organizational Plan, Maneuver Control System annex, and the vehicle system must communicate fully with the other digitized C^2 platforms.
2. Improve the capability of the BFVS-A3 target acquisition and fire control systems, include a ballistic fire solution for the main gun system and add a commander's independent thermal viewer for the vehicle commander.
3. Improve survivability.
4. Provide ventilated face pieces for Nuclear Biological and Chemical (NBC) protection for the dismount element while they are in the vehicle.
5. Provide a Position Navigation (POS/NAV) System consisting of an inertial system integrated with the GPS.
6. Maintain cross-country mobility with the MBT in forward speeds.

7. Provide integrated diagnostic/prognostic/BIT/BITE as a cost effective means of fault detection/isolation for the upgraded portions of the vehicle.

8. Cause no changes in crew and support personnel requirements.

This thesis focuses on only two of these issues (2 and 3), the capability of the BFVS-A3 target acquisition system and improved survivability. Further, the TEMP lists a number of Critical Operational Issues and Criteria. [Ref. 2: Annex 1] These include criteria 1.2.3, the M2/M3A3 must provide the BFV crew and unit an increased capability over the M2/M3A2 to acquire, engage and hit threat targets. Other characteristics and critical issues are not relevant to the modeling scope of this thesis. The relevant criteria may be divided into four issues for which this thesis will define MOEs and conduct analysis of the simulation results. These issues are :

1. detection,
2. engagement,
3. lethality, and
4. survivability.

A measure of effectiveness is defined as a parameter that evaluates the capability of the system to accomplish its assigned missions under a given set of conditions [Ref. 9: p. 36]. MOEs determine how test results will be judged. They are directly tied to critical issues in that the resolution of each issue is generally in terms of the evaluation of one or more MOEs.

1. Detection

The first issue considered was the ability of the BFVs to detect enemy threat vehicles. The BFVS-A3 is expected to provide detection of enemy threat vehicles at greater ranges than the BFVS-A2 due to the IBAS. The MOE used to quantify this aspect of the comparison is :

MOE 1 - Range of initial detection by defensive platoon minus range of initial detection by attacking platoon.

The Head-to-Head scenario will be used to gather data for this MOE. In this scenario the defending force should normally achieve a first detection of the mobile advancing force before the approaching force will achieve detection of a prepared defensive position. By taking the difference between the ranges of first detection, the MOE represents the distance through which the attacking force must travel while the defending unit can observe, withdraw prior to contact, or engage with indirect fire weapons while still remaining undetected. The defender may also engage with its direct fire weapons to try and cause casualties at maximum range, if the intention is to stay and fight from this position. The use of direct fire weapons with large firing signatures, however, may provide an easier first detection to the enemy. The MOE is a distance which can be converted to a time by knowing the rate of advance of the attacking vehicles. Should the defender have a mission to hold his position for a particular time, and the MOE time is greater than this time, the defender may withdraw prior to detection and engagement. If not, the defender can still get an idea of the length of time he must fight from this position while being engaged.

A comparison of this MOE between the scenario with the BFVS-A2 in defense and the scenario with the BFVS-A3 in defense will show whether the BFVS-A3 displays an improved detection capability as described. A larger value of this MOE is preferred by the defender. It provides the defender the greater flexibility and chance to inflict casualties on the enemy. A small value of the MOE implies that the defender will not have this stand-off time where he has a distinct advantage.

2. Engagement

The ability of the BFVS-A3 to engage targets will be determined by the ability to hit and kill the target at greatest range. Ability to engage is addressed in part by detection, covered by MOE 1, and lethality which will be discussed shortly. Another aspect of

engagement is the desire to engage at maximum range in order to attrit the enemy quickly in the battle and provide time to bring all the elements of combat power effectively against the enemy. For the Force-on-Force test scenario, a MOE can be defined showing which BFV can achieve effective engagements at greater range by:

MOE 2 - The maximum range of a shot which resulted in an enemy kill.

3. Lethality

The third issue is the lethality of the BFVS. The greater number of vehicle kills the platoon is able to inflict on an attacking enemy, the greater the ability to hold the defensive position. The measure of performance taken from the Force-on-Force test scenario used for this issue is:

MOE 3 - The number of enemy vehicles killed before completion of the battle.

The Force-on-Force battle will end when all four BFVs are destroyed. This result will occur in all runs of this scenario with sixteen enemy vehicles attacking four vehicles which will remain in position until either force is destroyed. In all scenario runs, the enemy's force advantage prevailed.

4. Survivability

The fourth issue is the survivability of the BFVS. The survivability is measured by the ability of the BFVS to survive enemy engagements. The measure of performance using the Force-on-Force test to describe this issue is:

MOE 4 - The number of enemy shots fired before the BFV platoon is destroyed.

Although, hopefully, a platoon will not have to fight in a position until all vehicles are killed, this MOE provides a measure of time the platoon can survive on a position

under attack. Both tested vehicles may be equally susceptible to tank rounds, however the BFVS-A3 with a Missile Countermeasure Device should survive longer under threat from the anti-tank missiles carried by the BMP vehicles. This MOE will look at whether the BFVS-A3 is able to survive longer than the BFVS-A2 when attacked by tanks and BMPs.

The next chapter will discuss the Janus simulation and some of the functions it provides to model the scenarios that have been described in this chapter. Further, it will detail how the BFVs will be modeled within the Janus database and finally, the data that will be captured from the simulation to produce values for the MOEs.

III. JANUS COMBAT MODEL

The wargaming simulation called Janus is an interactive, closed, stochastic, combat simulation. Initially a two-sided ground combat model, it has developed to where later versions feature multiple sides, fratricide and include some basic air and amphibious operations. The interactive nature of the simulation allows the workstation operator, either the military analyst or the unit controller, to make real-time decisions or changes in the combat operation to provide interplay between the operators. The simulation is closed, meaning that the disposition of opposing forces is not known to the operator until a system under his control detects the enemy system. Janus, as with many other simulations is stochastic, it therefore uses a random number generator and probabilities to determine the results of detections and engagements.

The simulation relies on accurate modeling of the terrain and the weapon platforms to produce a realistic model of a combat situation. The simulation uses digitized terrain from the Defense Mapping Agency to portray elevation, roads, rivers and vegetation. This storage of terrain attributes allows Janus to realistically model visibility and movement. The simulation stores many attributes for each weapon and weapon platform. These attributes, together, model the systems capabilities in the given terrain and weather conditions to simulate detections and engagements of actual combat. Janus provides a tool to both the training environment and analytical agencies to examine a tactical plan, a new or modified weapon system to reveal weaknesses or provide a quantitative measure of achievement.

A. DATABASE REQUIREMENTS

The Janus Combat Systems database describes systems extensively and is quite complex. The database is divided into sections, including system, weapon, sensor, chemical, engineer, and weather characteristics. Relevant to this thesis are the system, weapon, and sensor characteristics. System characteristics include general characteristics

such as maximum speed, maximum visibility, maximum weapon range, and crew size; functional characteristics such as firing type, mover type, swim type, and weight and volume data; weapon characteristics include aim and reload times, rounds per trigger pull and round velocity. Sensor characteristics include fields of view and temperature or contrast tables for thermal or optical sensors respectively.

This thesis required the above database information for four systems, the BFVS-A2, BFVS-A3 and enemy systems T-72 tank and BMP-2. The characteristics used for the enemy systems were the values in the TRADOC Research and Analysis Command (TRAC) - Monterey, Janus version 6.0 database with some corrections made where the data were missing or incorrect according to the field manual "The Soviet Army - Troops, Organization and Equipment" [Ref. 7]. It is not crucial to this thesis that the enemy system data be precisely correct as long as both the BFVS-A2 and BFVS-A3 were compared against the same enemy vehicle definitions. Vehicle characteristics and basic weapon characteristics have been confirmed with available references, however, sensor, probability of hit (Ph), and probability of kill (Pk) data from the TRAC - Monterey Janus database have not been confirmed with any other source.

The data used to model the BFVS-A2 and BFVS-A3 are contained in Appendix A. Most of the data is the same for both vehicles for the general and functional characteristics. The following two sections will describe the data requirements relevant to the particular vehicles. The areas of the database where these differences mostly occur are in the sensor characteristics and the probability of hit (Ph) tables.

1. BFVS-A2 Model

The Janus BFVS-A2 system has been created with the characteristics, sensors and weapon loads in accordance with TEMP, where covered, and by relevant Field Manuals or data from other military sources otherwise. All data used in this thesis are unclassified. Janus sensor data requires the measurements for narrow and wide field of view and a table of temperature or contrast verses cycles per milliradian for each of two sensors on the

system. The field of vision (FOV) measurements were obtained from the US Army Materiel System Analysis Agency (AMSAA). The system has, as its primary sensor, a First Generation Forward Looking Infrared (FLIR) sight. Since this is a thermal sensor, a table of twenty values of temperature verses cycles per milliradian which make up the Mean Resolvable Temperature (MRT) curve are required. The MRT curve was obtained from the TRAC Janus database. The system will search with a primary sensor for twenty seconds. If no detections are made it will switch to the alternate sensor for a further twenty seconds before switching back to the primary. If it is an optical sensor then twenty values for contrast verses cycles per milliradian are required. These values form the Mean Resolvable Contrast (MRC) curve. The MRC curve is equivalent to the MRT curve where the sensor is optical instead of thermal. The alternate sensor of the BFVS-A2 is an optical sensor. The MRC values were obtained from the TRAC - Monterey JLINK database. The idea of resolvable cycles across a target can be related to the amount of detailed information required to identify a target. The higher the number of cycles and the higher the contrast, the better the acquisition. This data is used with the line of sight (LOS) algorithms and the terrain database by Janus to determine when detections occur.

Janus provides a graphical scenario verification function which will read the database characteristics for a system against another system and produce reports. These reports allow the controller to look at sensor, Ph and Pk information to detect errors or missing data. One graphical report available is a plot of detection probability by range for the two sensors carried on the observing system. Figure 6 shows this plot for the BFVS-A2 detecting the BFVS-A3.

The engagements are determined by the characteristics of the weapons carried by the system and the Ph and Pk tables contained in the database. The Janus database contains Ph and Pk tables for all weapon against system combinations. The data contained in these tables may be the same across similar groups of target systems, for example the Ph table for the TOW system engaging a BMP vehicle or a BTR vehicle may be the same. The Ph tables used in this thesis for the TOW IIB weapon against the BMP and T-72 were obtained from the Infantry School, Ft Benning, Georgia. The Ph table gives the

probability of hit for a weapon against a target system within five different range bands and for sixteen different firer / target postures. These postures include all combinations of the firer being stationary and moving, the target being stationary and moving, the target defilade or exposed and the target head-on or flank-on. Appendix A contains all the relevant database values used to model the BFVS-A2 in Janus for the two battle scenarios used in this thesis.

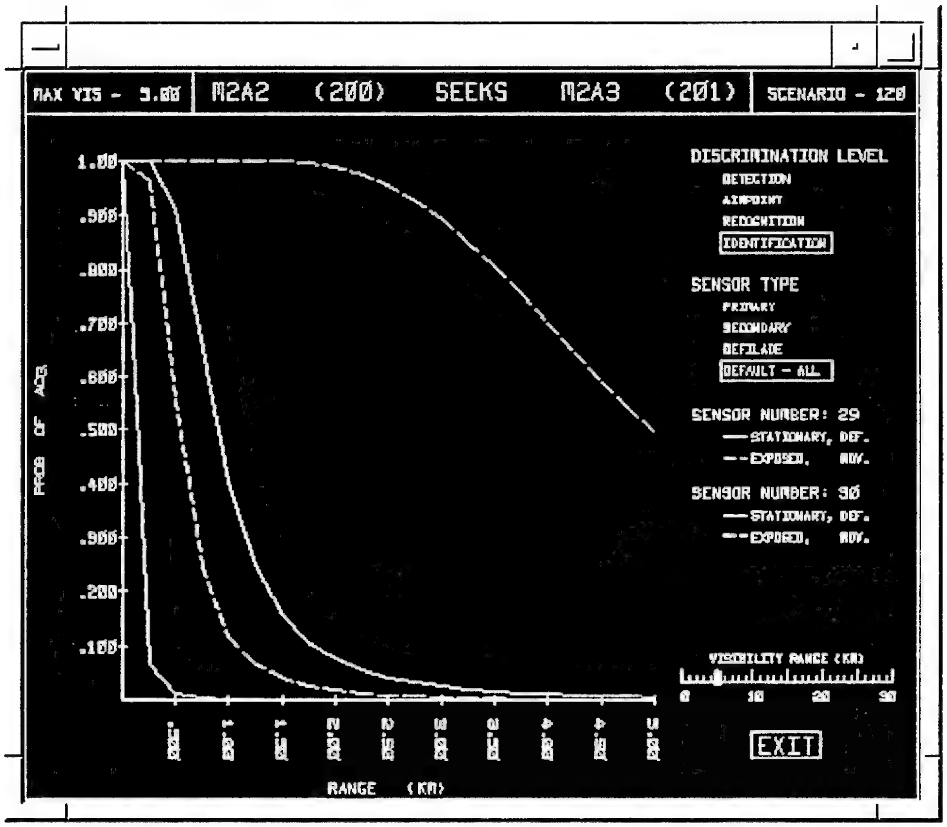


Figure 6. Probability of Detection verses Range for BFVS-A2 against BFVS-A3

2. BFVS-A3 Model

The Janus BFVS-A3 system was created from the baseline BFVS-A2 system with the modifications as described in this section. The entries that were considered to be affected by the A3 modifications are :

a. weight,

b. lay and aim times of the TOW and 25mm weapon systems,

c. the MRT / MRC tables for each sensor,

d. Ph tables for BFVS-A3 engaging enemy systems,

e. Ph table for enemy systems engaging the BFVS-A3.

The weight of the BFVS-A3 has increased to 66,450 lb. This increase may affect the cross country mobility in certain terrain types. Although this is not likely to affect the outcome of this simulation, it has been included in the BFVS-A3 system. The IBAS and BELRF systems affect the lay and aim times of the weapon systems. The Janus database interprets lay time as the average time in seconds to lay a weapon for direction. This time accounts for the fact that a weapon, even if pointed at a target, must be adjusted to select and bring cross hairs onto an aim point. The aim time is the time to aim the weapon once it has been laid for direction or the time to re-aim the weapon for a second shot. The IBAS has an auto-tracking capability and upgraded fire control hardware and software which is expected to decrease the lay and aim times by 50 %.

The IBAS provides a second generation FLIR which has a different MRT curve than the first generation FLIR on the BFVS-A2. The table of temperature verses cycles per milliradian which make up the MRT curve used in this model were obtained from the Program Manager Office - Bradley Fighting Vehicle System. In addition, the measures of narrow and wide field of view are changed from the BFVS-A2 sight unit. The BFVS-A3 field of view measurements were obtained from AMSAA. Figure 7 shows the graphical scenario verification display of probability of detection against range for the sensors on the BFVS-A3 against the BFVS-A2.

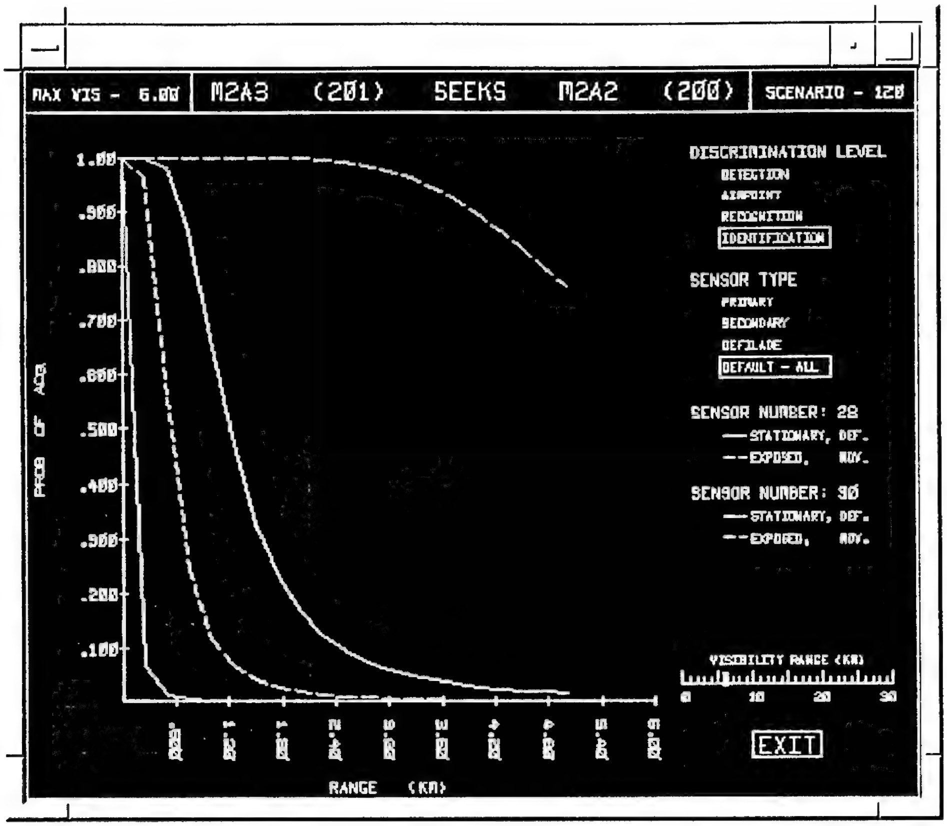


Figure 7. Probability of Detection verses Range for BFVS-A3 against BFVS-A2

Since the IBAS provides the gunner with a much improved resolution at greater range than the previous sight, it is expected that the Ph shall improve. In addition, the use of the BELRF will not only provide a precise range to the target for a better fire control solution but will eliminate the need for "sensing rounds" to guide the weapon system on to the target. This will also improve the probability of hit for the BFVS-A3. The Ph values for the BFVS-A2 against a BMP range from 0.2 to 0.9 depending on posture of firer and target, and range to target. As an initial estimate of the effect on Ph, an improvement of 0.05 was used across the range of Ph values from that of the BFVS-A2.

B. JANUS FUNCTIONS

The Janus simulation provides many functions which allow the user to as accurately as possible model combat between two opposing forces. This section will define some of these functions and describe how they are used to achieve an accurate model of the actions required in the scenarios as described in Chapter II. Each simulation run has two phases, the planning phase and the execution phase. During the planning phase the vehicle icons are positioned in their start locations. The controller is also able to enter planned movement routes for the vehicles to follow in the execution phase. In both scenarios, the start locations are approximately 6 - 7 km between forces and out of line of sight. The controller also sets each vehicle's field of view with respect to width and center of arc. The narrower the arc, the greater the probability of detection within that arc. The vehicles that are moving will look throughout a 360 degree field of view and once stationary will revert to their pre-set field of view. By using pre-determined routes and the following functions each run of the scenario will follow the same actions except for changes caused by the random effects of the simulation, with minimal controller actions during the execution phase of the run. Further the pre-determined aspects of the scenarios with the BFVS-A2 can be copied to scenarios with the BFVS-A3 to ensure these scenarios are the same except for vehicle changes and the results caused by those differences. Vehicle routes are entered as straight lines between nodes. The nodes may be "stop", "go" or "timed" nodes. A vehicle will pass through a "go" node in the direction of the next leg. If it reaches a "stop" node, it will remain at the node until told to go by the controller. A "timed" node will hold a vehicle in that location until the entered time is reached on the game clock. In the execution phase the game clock starts, all units commence using their sensors and units with movement routes starting at "go" nodes will commence moving.

The use of "stop" nodes on each bound of the vehicle route allows the controller to replicate the bounding overwatch method of movement. Further, this function allows the controller to maintain the formation of the attacking force as the vehicles move over

different terrain. This is useful in the Force-on-Force scenario where there are different vehicles which will move at varying speeds over the different terrain types. The "stop" nodes allow the controller to regain the formation before the next leg commences and stops the trailing vehicles (BMPs) from overtaking the leading tanks (T-72s) which move more slowly when conducting creek crossing on the approach.

The sprint function allows the user to make an individual vehicle or group of vehicles move at maximum speed instead of formation speed. This is useful when a vehicle falls behind its formation due to a difficult creek crossing or similar event. The user may put that vehicle in sprint mode long enough to catch up with the other vehicles in the formation. This is a useful function for modeling the realistic movement of vehicles in formation.

A moving vehicle is in an exposed state. Once it halts the status changes to partial defilade or equivalently a "hull down" posture. In this status the vehicle can detect and engage enemy units. However, it has some additional protection from observation, representing the vehicle choosing a position to halt with some cover or concealment. The defilade function allows a vehicle to be put in full defilade or a "turret down" posture. In this status the vehicle detects but does not engage except in self defense. Janus also provides a function "prepos", which allows the user in the planning phase to site prepared fighting positions for personnel or vehicles. Vehicles in a "prepos" position will acquire in a full defilade status then change to partial defilade to fire, then return to full defilade. The "prepos" function was used to model the deliberate defensive position of the BFV platoon in the Force-on-Force scenario.

C. SCENARIOS

In the last chapter the two battle scenarios were discussed in some detail. These were the Head-to-Head Test and the Force-on-Force Test. This thesis required the execution of two scenarios with the roles of the BFVS-A2 and BFVS-A3 reversed; therefore, four Janus scenarios have been run. These scenarios are numbered 120, 150,

200 and 250. This thesis will refer to these scenario numbers so that any reader with access to the Janus files used in this study will be able to match the numbers to file names.

The scenarios are defined as follows:

a. Scenario 120 - Head-to-Head Test with BFVS-A2 in hasty defense and BFVS-A3 in attacking.

b. Scenario 150 - Head-to-Head Test with BFVS-A3 in hasty defense and BFVS-A2 in attacking.

c. Scenario 200 - Force-on-Force Test with BFVS-A2 in deliberate defense and Soviet style tank heavy company attacking.

d. Scenario 250 - Force-on-Force Test with BFVS-A3 in deliberate defense and Soviet style tank heavy company attacking.

Janus screens depicting these scenarios can be found in Appendix C. The figures show the force locations in the Head-to-Head scenario, together with the field of view of the defending BFVs and the routes used by the attacking vehicles. The Janus screens of the Force-on-Force scenario show the tank heavy Company's initial location and the field of view of the defending BFVs.

D. SIMULATION RUNS AND DATA COLLECTION

1. Number of Runs

The conduct of a single Janus battle as run in this thesis, requires interaction by the controller. It is therefore a time consuming process to conduct a large number of runs in each of the four scenarios. All four scenarios are required to produce a value in each MOE. It was therefore preferable to keep the number of runs in each scenario as small as possible while still providing useful results. The analysis of the data will be discussed in the next chapter, however previous Janus studies suggest 10 - 12 runs are usually required to provide sufficient variability in outcome that can be analyzed. After noting the variation in values produced by the first few runs, it was decided to conduct 20 runs of each

scenario for further analysis. The suitability of conducting 20 runs will be investigated in the next chapter.

2. Postprocessing Files

As each simulation run is made, Janus records all the data compiled during the battle. These files include data such as movement routes, detections, direct fire shots, artillery impacts and kills. With these files the controller is able to replay the battle to analyze it more closely, or produce postprocessing files. The postprocessing files provide printed or screen reports containing killer-victim scoreboards, detection reports or artillery reports, as the controller requires to conduct the analysis.

To collect the data necessary to this thesis, the Direct Fire, Coroner's and Detection reports were generated by the postprocessing function. An example of the reports contained in the postprocessor files is shown in Appendix D. The data collection included:

a. Scenario 120 - range of defender's first detection of an attacking vehicle;
range of attacker's first detection of a defending vehicle.

b. Scenario 150 - range of defender's first detection of an attacking vehicle;
range of attacker's first detection of a defending vehicle.

c. Scenario 200 - range of longest direct fire shot which resulted in a kill,
number of enemy vehicles killed;
number of enemy shots or bursts fired before last defending vehicle is destroyed.

d. Scenario 250 - range of longest direct fire shot which resulted in a kill;
number of enemy vehicles killed;
number of enemy shots or bursts fired before last defending vehicle is destroyed.

The next chapter will discuss the analysis of the data collected. It will include the reasons for accepting 20 as the number of runs for data collection, then discuss the statistical tests used to interpret the data.

IV. DATA ANALYSIS

The raw data gathered from the postprocessing files is shown in Appendix E. The data from the scenarios 120 and 150 were manipulated as discussed in the previous chapter to produce MOE 1 for the BFVS-A2 and the BFVS-A3. The rest of the data required no manipulation. The data set produced is shown in Table 1. It constitutes two samples of 20 values in each of four MOEs to be compared.

Run	MOE1A2	MOE1A3	MOE2A2	MOE2A3	MOE3A2	MOE3A3	MOE4A2	MOE4A3
1	1.883	2.302	3.66	3.24	7	12	71	68
2	1.146	1.601	3.52	3.39	7	7	39	41
3	1.912	2.618	3.70	3.26	2	5	46	47
4	2.160	1.705	3.38	3.18	7	5	75	87
5	0.253	1.681	3.65	3.51	4	4	36	79
6	1.508	5.285	3.36	3.38	5	13	33	69
7	2.119	2.632	3.26	3.26	2	5	47	65
8	1.839	2.645	3.56	3.47	10	11	56	68
9	1.703	5.439	3.36	3.65	3	4	48	62
10	0.091	1.440	3.71	3.71	3	2	25	59
11	1.046	5.359	2.65	3.74	1	5	40	59
12	-1.161	2.547	3.66	3.55	4	3	61	20
13	1.369	1.796	3.39	3.50	3	5	24	69
14	4.413	2.512	3.60	3.56	3	4	47	41
15	1.098	1.820	3.62	3.46	4	5	75	58
16	1.324	1.186	3.36	3.12	4	11	56	100
17	2.073	0.811	3.00	3.62	1	8	21	28
18	-0.137	1.681	3.40	3.36	1	5	66	32
19	1.285	3.236	3.68	3.44	4	4	38	52
20	1.990	1.457	3.58	3.44	2	6	35	60

Table 1. Data set produced by simulations

The goal of this thesis entails making inferences about the comparison of the data for each vehicle. The primary result to be determined by this analysis is whether there is a change in the mean of each MOE between the BFVS-A2 and BFVS-A3. This analysis will compare the two sample means based on two methods. The first is a two sample T-test method based on the normal distribution. The development of this test will provide a way to investigate whether twenty runs are sufficient to provide enough power to the test. The second is a non-parametric method known as the Mann-Whitney-Wilcoxon test [Ref. 10:p. 159]. This test is less powerful than the two sample T-test but is non-parametric in

nature, and was used to substantiate or oppose the results found from the first test. This chapter will also look at the assumptions involved in the tests and the results shown in each MOE, by each method.

A. TWO SAMPLE T-TEST

The problem to be analyzed, is to compare two populations of possible MOE values, where the sample size is small and the population variances are unknown. Devore [Ref. 11:pp 357-359] shows that a two sample T-test is appropriate in this case based on two assumptions. The assumptions are :

1. Both populations are normal, so that $X_1 .. X_m$ is a random sample from a normal distribution and so is $Y_1 .. Y_n$, with the Xs and Ys independent of one another.

2. Values of the two population variances σ^2_x and σ^2_y are equal.

The test statistic for testing $H_o : \mu_x - \mu_y = \Delta$, under these two assumptions is then

$$t = \frac{\bar{x} - \bar{y} - \Delta}{s_p \sqrt{\frac{1}{m} + \frac{1}{n}}}$$

with m + n - 2 degrees of freedom, where m and n are the two sample sizes. The alternative hypothesis may be one of the following with the respective rejection regions :

$H_a : \mu_x - \mu_y > \Delta$	$t \geq t_{\alpha, m+n-2}$
$H_a : \mu_x - \mu_y < \Delta$	$t \leq - t_{\alpha, m+n-2}$
$H_a : \mu_x - \mu_y \neq \Delta$	$t \geq t_{\alpha/2, m+n-2}$ or $t \leq - t_{\alpha/2, m+n-2}$

The goal of this research is to determine if the BFVS-A3 is significantly better than the BFVS-A2. Initially, it is desired to determine if there is any difference between vehicles. In this case, Δ is equal to zero and the null hypothesis to be tested is

$$H_o : \mu_{A3} = \mu_{A2}$$

This asserts that there is no difference between the distribution of the A3 data and the A2 data. In order to conclude that there is a difference, the null hypothesis must be rejected. The alternative hypothesis of interest is

$$H_o : \mu_{A3} > \mu_{A2}$$

This hypothesis is appropriate if the A3 data has shown improvement over the A2 data. In order to reject the null hypothesis the test statistic t must be greater than the critical value $t_{\alpha,\, m+n-2}$. Before conducting the hypothesis tests, it was decided to investigate whether the sample size would provide the power desired in the test. Additionally, a first look graphical analysis and an examination of the assumptions were conducted.

1. Analysis of the Sample Size

The simulation is conducted a number of times so that the data produces a sample mean and variance which are good estimators of the true population parameters. As the number of runs (n) increase, the sample should more closely resemble the true distribution. On the other hand, the sample size is limited by the time available to conduct the simulations. In this study, all scenarios were run an equal number of times, therefore sample sizes, m and n, for each MOE are equal.

Investigating the power of the test is important in determining how large the sample sizes should be. The power of a test is the probability of rejecting the null hypothesis when it is false [Ref. 12:p. 400]. The power of the two sample T-test depends on four factors : the real difference between the sample means, the significance level, α, of the test, the population standard deviation, σ, and the sample sizes, m and n. The power of the test may be determined using the Operating Characteristic (OC) curves for a particular level of significance α. OC curves show the probability of accepting the null hypothesis verses the mean in the one sample case, and verses the scaled difference between means, d, in the two sample case, for various values of the size n of the samples. Bowker and Lieberman [Ref. 13:pp. 168-170] provides the development of the two sided

procedure and a summary of the steps for the one sided case to determine the required sample size. In the one sided procedure which is relevant to this use of the two sample T-test, n` is determined from the graph of OC curves [Ref. 13:p.132], for given α, β which is equal to (1- power), and

$$d = (\mu_{A3} - \mu_{A2}) / 2\sigma$$

where the sample size n = (n`+1)/2 and $\sigma = \sigma_{A3} = \sigma_{A2}$ is the true standard deviation of the samples, with the standard deviations assumed equal. The pooled sample standard deviation can be used as an estimator of σ [Ref. 11:p. 358], therefore

$$s_p = \sqrt{\frac{s_{A2}^2 + s_{A3}^2}{2}} \qquad \text{if m = n}$$

or

$$s_p = \sqrt{\frac{(m-1)s_{A2}^2 + (n-1)s_{A3}^2}{m+n-2}} \qquad \text{if m} \neq \text{n}$$

where m = number of BFVS-A2 observations, and

n = number of BFVS-A3 observations.

This procedure can be reversed in order to determine the power of the test from the same graph of OC curves, for a given n`,α, and

$$d = \Delta / 2\sigma$$

where Δ is the difference between means to be tested by the two sample T-test. Figure 6.12 of Bowker and Leiberman shows the OC curves plotted for a level of significance, α, equal to 0.05. Initially a sample size of 20 runs was obtained from which s_p was calculated for each MOE, and hence n` equal to 39 was used.

For the concerned reader, Bowker and Lieberman [Ref. 13:p. 171] states that the OC curve, for n` equal to 2n-1, from Figure 6.12 or 6.13 of their book is used to determine the power of the test in the one sided case. In this study, Figure 6.12 for $\alpha$ equal to 0.05, and n` equal to 39 was used.

Therefore the remaining parameter required is Δ, the value of the difference between the vehicles in each MOE that is considered significant. It was decided that for

detection and engagement ranges, a Δ of 500 meters would provide the defensive BFVs the time to fire the two missiles carried in the launcher and reload. This decision is based on an attacking speed of approximately 20 kilometers per hour, therefore 1.5 minutes in extra standoff time or engagement time. For MOE 2 and MOE 4, approximately 30 percent of the range of values was used. Therefore, it was considered that three extra kills is significant to the lethality comparison and 20 extra shots significant to survivability. The values for power based on the pooled estimated standard deviation s_p, Δ, n,and the OC curves for $\alpha = 0.05$, for each MOE are shown in Table 2.

	n`	Δ	s_p	d	power
MOE 1	39	0.5	1.253911	0.1994	0.20
MOE 2	39	0.5	0.222002	1.1261	1.00
MOE 3	39	3	2.780335	0.5395	0.95
MOE 4	39	20	18.152969	0.5509	0.96

Table 2. Values of power calculated for each MOE

The above results show that n = 20 is an acceptable sample size to detect the difference Δ in each MOE except MOE 1, with at least 90 percent probability. The MOE 1 values for both vehicles have some peculiarities which create large variances and hence require a large n. For the BFVS-A2, there was one run (#14) in which the attacker didn't achieve detection at all, and one run (#12) where the attacker detected 1161 meters prior to the defender. In the BFVS-A3 data, there are three runs in which the attacker did not achieve detection. After discussions with experienced armored vehicle commanders and personnel who have witnessed the signature of the TOW missile fired, it was considered unrealistic to not get a detection after the number of missiles fired by the defending BFVs. In addition, the moving attacking vehicles should not have had detection on the stationary, deliberate defensive position vehicles, 1161 meters prior to the defender's detection. Therefore, these two and three entries have been removed from the samples of MOE 1 for their respective vehicles. The s_p value for MOE 1 becomes 0.672925 and the power is

therefore increased to approximately 0.75. Given these results, n = 20 has been accepted as sufficient to continue with the analysis of the means.

2. Graphical Analysis

A graphical approach was used, for a first comparison between the samples. Figures 8 to 11 show side by side boxplots of the data. The boxplot provides a quick impression of the distribution of the data. Shown is the median of the data, the spread of the central 50 percent is the box, and the whiskers show values in the tails of the distribution. Values which occur outside 1.5 times the interquartile range are shown as outliers by a single line.

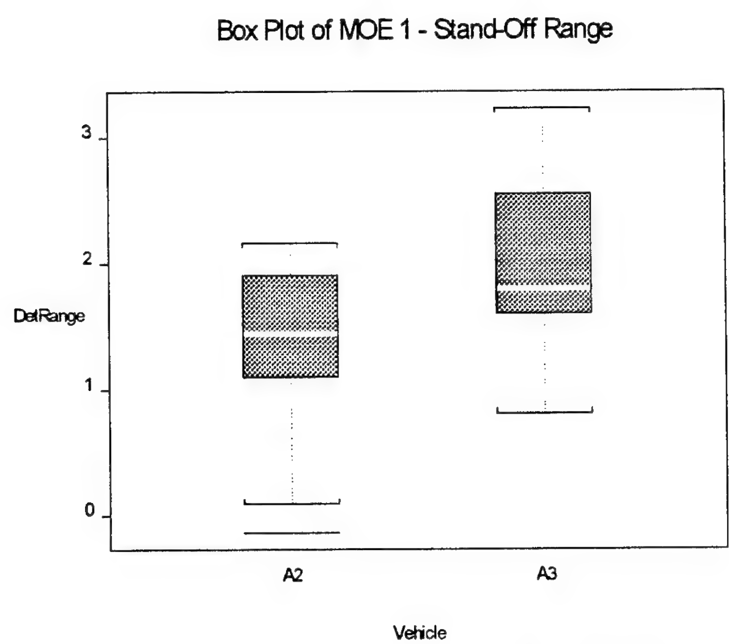


Figure 8. Side by Side Box Plots of MOE 1

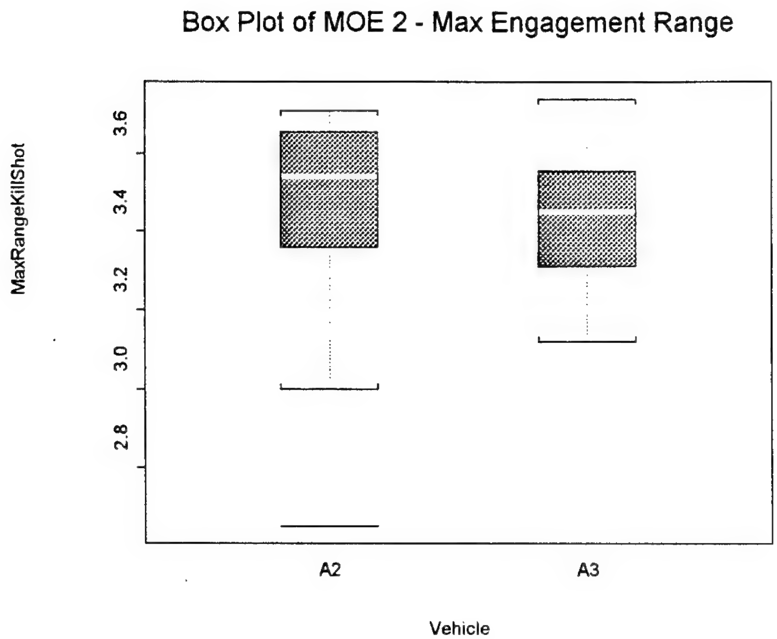


Figure 9. Side by Side Box Plot of MOE 2

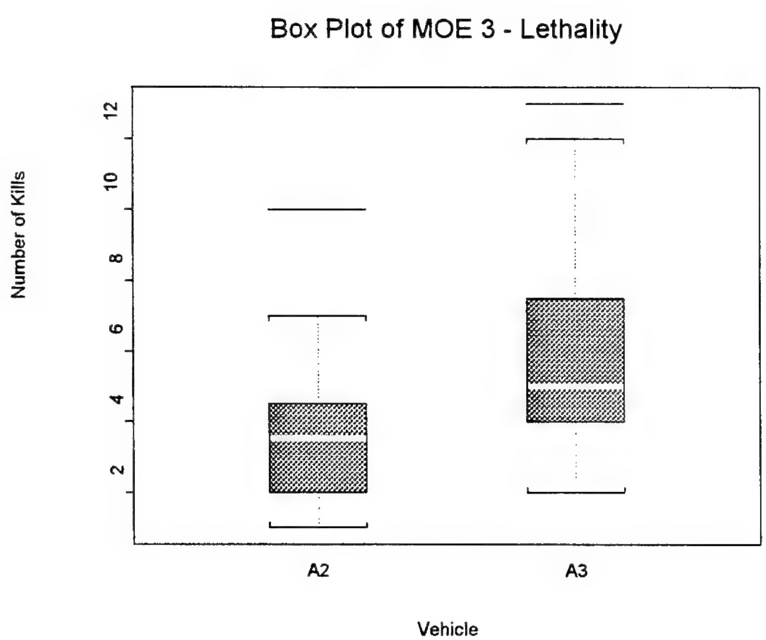


Figure 10. Side by Side Box Plots of MOE 3

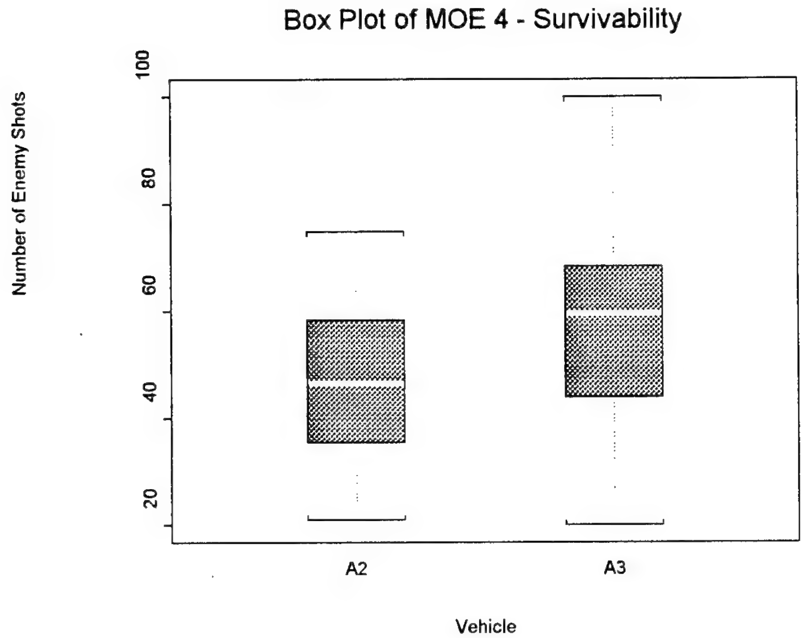


Figure 11. Side by Side Box Plots of MOE 4

Figure 8 shows that for MOE 1, the median value for the BFVS-A3 is greater than the BFVS-A2. In addition, the variances look reasonably close. Figure 9 shows the medians to be very close, however the BFVS-A2 has a slightly higher maximum engagement range. The BFVS-A3 does however, have the longest shot overall, and has fewer shots at the low end of the range. Figure 10 shows a more expected result, with the BFVS-A3 having a higher median in MOE 3, and with variance slightly greater shown by the BFVS-A3. Figure 11 shows, again, a higher median for the BFVS-A3, however, for this MOE, there is a greater increase in variance shown. The following sections will use the sample means and standard deviations in a statistical comparison between the vehicles. Table 3 shows the mean and standard deviations for each MOE, for each vehicle. For MOE 1, the inconsistent values have been removed as discussed in the last section.

	MOE1A2	MOE1A3	MOE2A2	MOE2A3	MOE3A2	MOE3A3	MOE4A2	MOE4A3
Mean	1.3701	1.9806	3.4550	3.4420	3.8500	6.2000	46.9500	58.2000
Variance	0.4920	0.4112	0.0689	0.0296	5.6079	9.8526	274.1553	384.9053
Std Dev	0.7014	0.6413	0.2626	0.1721	2.3681	3.1389	16.5576	19.6190

Table 3. Descriptive Statistics for each MOE on each vehicle

A first look at the means suggests that in MOE 1, 3, and 4 some improvement has been shown by the data obtained. In the case of MOE 2, there is only a 13 meter difference over a range of approximately 3500 meters. This amount of difference could be attributed to randomness and hence looks as though there is no difference in maximum engagement range between the vehicles. The analysis will continue in the following sections with an investigation of the assumptions of the test and how the test is used to compare the samples of each MOE.

3. Test Assumptions

The two sample T-test assumes the samples are drawn from normal distributions. To investigate the validity of this assumption, Quantile - Quantile plots for the Normal Distribution were plotted. The results are shown in figures 12 to 15.

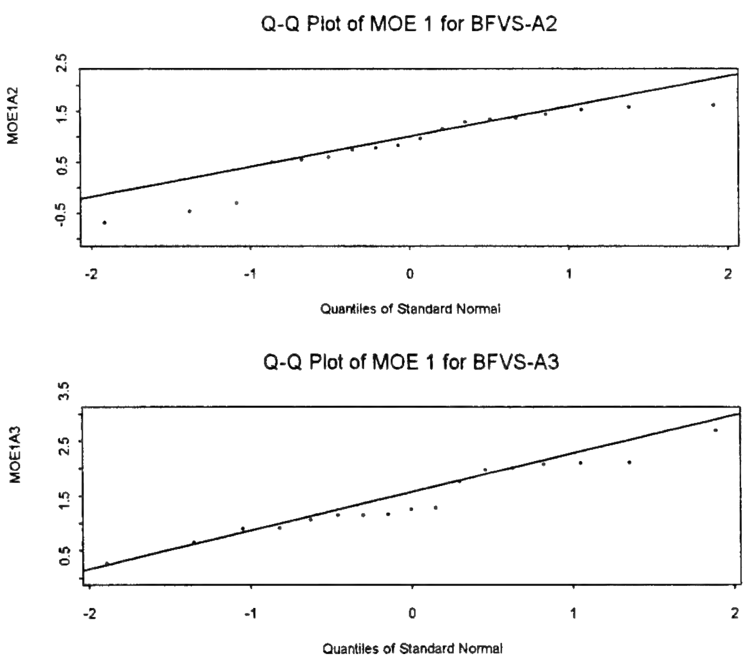


Figure 12. Q-Q Plots for MOE 1

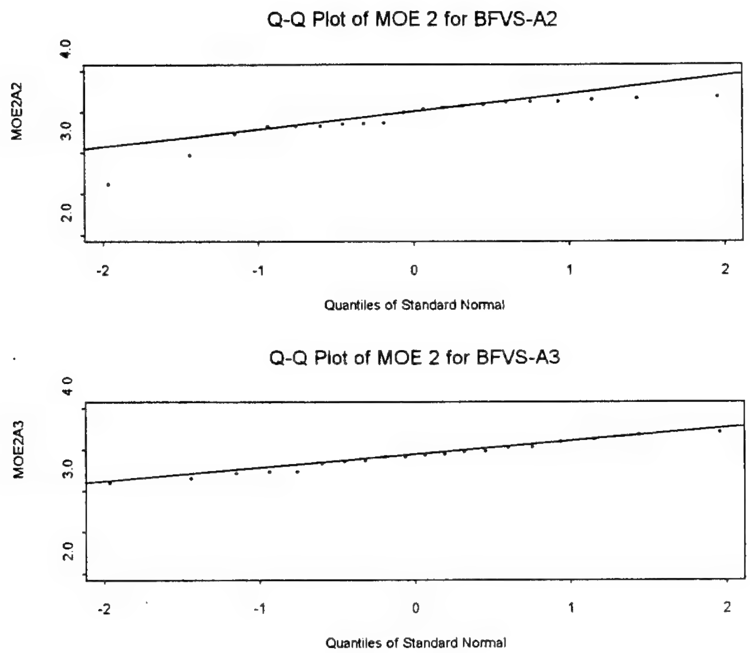


Figure 13. Q-Q Plots for MOE 2

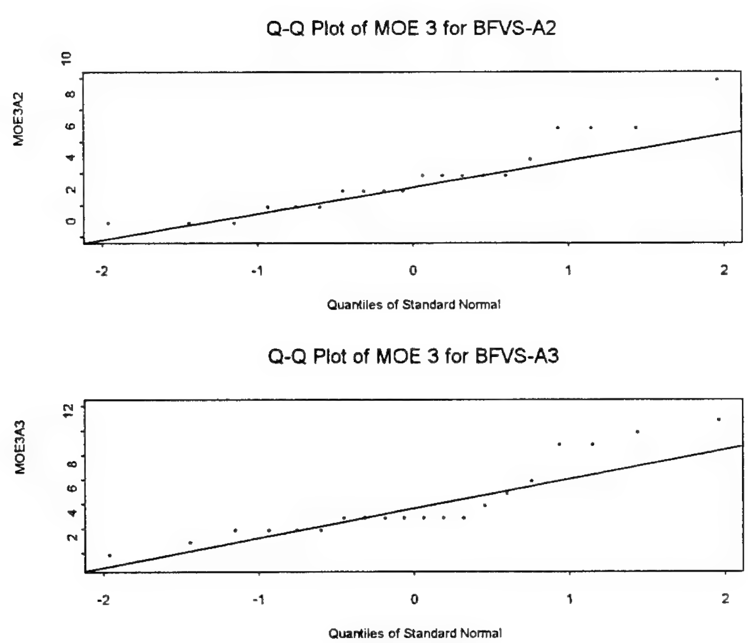
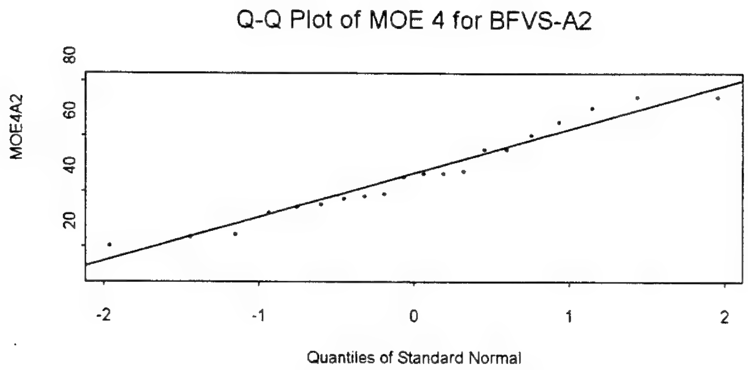


Figure 14. Q-Q Plots for MOE 3



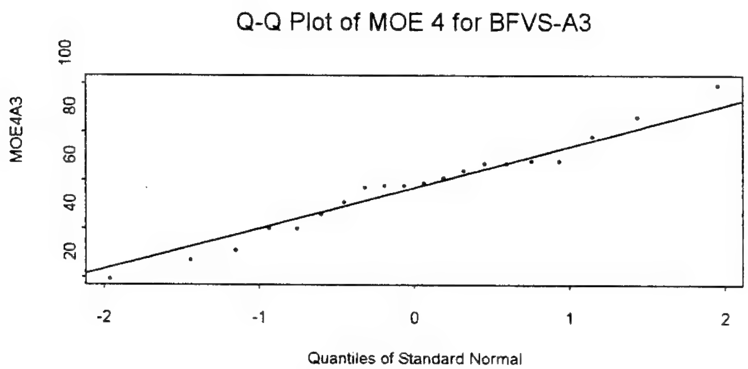


Figure 15. Q-Q Plots for MOE 4

A visual inspection of the Quantile-Quantile plots show that the sample data in each MOE could be approximated by a normal distribution. To backup this conclusion the Chi-squared Goodness of Fit test was conducted. The samples were compared to the normal distribution with the parameters taken from the sample. The test provides a p-value for which the hypothesis that the sample is normal can be rejected if it is significant. The results are shown in Table 4. The Chi-squared test provides no reason to reject the use of the normal distribution in the analysis. Further, the p-values appear to be spread uniformly over (0,1), as shown in Figure 16. Such a plot supports the simultaneous acceptance of the eight null hypotheses of normal distribution.

MOE	BFVS-A2			BFVS-A3		
	χ^2 Statistic	d.f.	p-value	χ^2 Statistic	d.f.	p-value
1	1.3333	2	0.5134	1.8824	2	0.3902
2	1.2000	3	0.7530	0.0000	3	0.1116
3	0.8000	3	0.8495	4.0000	3	0.2615
4	0.0000	3	1.0000	4.8000	3	0.1870

Table 4. Results of Chi-squared Goodness of Fit Test
for testing samples against Normal Distribution

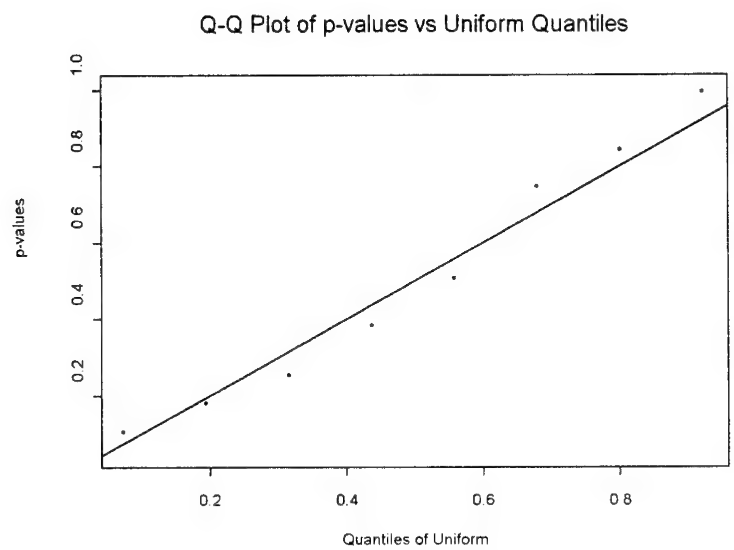


Figure 16. P-values verses Uniform (0,1) quantiles

The second assumption is that the two samples are drawn from distributions of equal variances. The boxplots shown earlier suggest, that in this problem, this assumption of equal variances may not hold, on the other hand the sample sizes are small. Devore [Ref. 11:p. 362] suggests that the two sample T-test is robust to mild departures from both of the assumptions and is more robust when m equals n than when m $\neq$ n. Further, it is suggested that the approach of simply "eye-balling" the sample variances to check for roughly the same magnitude is sufficient for this test. Figure 13 shows that the variances in each MOE are of approximately the same magnitude.

The following four sections will investigate the two sample T-test for each MOE. The test will examine a hypothesis based on a difference of Δ, where Δ is the magnitude of the difference considered significant from the analysis of sample size earlier. The analysis will continue with other hypotheses as necessary and show the confidence interval for Δ.

4. MOE 1

The test of hypothesis is $H_0 : \mu_{A3} - \mu_{A2} = \Delta$ against

$H_a : \mu_{A3} - \mu_{A2} > \Delta$

where $\Delta = 0.5$ provides a test for the BFVS-A3 showing a 0.5 kilometer improvement in MOE 1. The test statistic is

$$t = \frac{\overline{x}_{A3} - \overline{x}_{A2} - \Delta}{s_p \sqrt{\frac{1}{m} + \frac{1}{n}}}$$

$= 0.4855$ with a critical value of $t_{0.1,33} = 1.3077$

Therefore it cannot be rejected that the null hypothesis holds at $\alpha = 0.10$ significance. This result can be interpreted to mean that the data does not show a Δ difference between the samples. As a next step, it is tested whether there is any difference shown. Effectively, this is the same test with Δ equal to zero.

The test of hypothesis is $H_0 : \mu_{A3} = \mu_{A2}$ against

$H_a : \mu_{A3} > \mu_{A2}$

The test statistic is

$$t = \frac{\overline{x}_{A3} - \overline{x}_{A2}}{s_p \sqrt{\frac{1}{m} + \frac{1}{n}}}$$

$= 2.6823$

Therefore the test rejects the null hypothesis, indicating that a difference is shown between the samples with the BFVS-A3 showing the greater stand-off range. The one sided confidence interval was developed to establish the approximate size of the difference. The

lower bound of the one sided confidence interval will provide the measure of Δ which will just reject the hypothesis test shown above. Therefore, it is the lower bound of the improvement shown by the BFVS-A3 vehicle. The 90 % one-sided confidence interval for Δ is given by

$$(\bar{x}_{A3} - \bar{x}_{A2} - t_{\alpha/2,m+n-2} * s_p \sqrt{\frac{1}{m} + \frac{1}{n}}, \infty)$$

(0.6105 - 1.3077 * 0.672925 * 0.3382, ∞)

(0.6105 - 0.2976, ∞)

(0.3129, ∞)

This lower 90 percent confidence interval suggests the BFVS-A3 will achieve approximately a 313 meter or better improvement over the BFVS-A2.

5. MOE 2

The test of hypothesis for MOE 2 is the same as above, with the same Δ considered significant. The test statistic t = - 7.3074 with a critical value $t_{\alpha,38}$ = 1.3042. Therefore the null hypothesis cannot be rejected once again. Testing as before, for a difference equal to zero, provides test statistic t = -0.1852. This test shows that the BFVS-A3 data cannot support a statement of improvement over the BFVS-A2. The two-sided 90% confidence interval for Δ is given by

$$(\bar{x}_{A3} - \bar{x}_{A2} \pm t_{\alpha/2,m+n-2} * s_p \sqrt{\frac{1}{m} + \frac{1}{n}})$$

(- 0.0130 ± 1.6860 * 0.2220 * 0.3162)

(- 0.0130 ± 0.1184)

(- 0.1314, 0.1054)

6. MOE 3

This MOE examines the lethality of the BFVs. The same test is used on the number of kills the BFVs inflict on the attacking enemy. The hypothesis tests for an improvement by the BFVS-A3 of 3 kills over the BFVS-A2. The test statistic t= -0.7393. Therefore against a critical value of $t_{\alpha, 38}$ = 1.3042, the null hypothesis cannot be rejected. Testing as previous, for a difference equal to zero, provides test statistic t = 2.6728. It can be concluded then that the data does not show a difference of 3 kills between the vehicles, however it does show some measure of improvement by the BFVS-A3. A one-sided 90 % confidence interval for Δ is given by

$$(\bar{x}_{A3} - \bar{x}_{A2} - t_{\alpha/2, m+n-2} * s_p \sqrt{\frac{1}{m} + \frac{1}{n}}, \infty)$$

(6.2 - 3.85 - 1.3042 * 2.7803 * 0.3162, ∞)

(2.35 - 1.1466, ∞)

(1.2034, ∞)

7. MOE 4

This MOE examines the survivability of the BFVs. The same test is used on the number of shots the BFVs receive from the attacking enemy. The first hypothesis tests for an improvement by the BFVS-A3 of 20 shots over the BFVS-A2. The test statistic t = -1.5243. Therefore against a critical value of $t_{\alpha, 38}$ = 1.3042, the null hypothesis cannot be rejected. The second hypothesis is a test for any improvement shown by the BFVS-A3. The test statistic t = 1.9598, therefore the test shows some improvement but not the difference initially considered significant. A one-sided 90 % confidence interval for Δ is given by

$$(\bar{x}_{A3} - \bar{x}_{A2} - t_{\alpha/2, m+n-2} * s_p \sqrt{\frac{1}{m} + \frac{1}{n}}, \infty)$$

(58.2 - 46.95 - 1.3042 * 18.153 * 0.3162, ∞)

(11.25 - 7.4861, ∞)

(3.7639, ∞)

The method used in this section has made an assumption that the samples are being drawn from a normal distribution. A non-parametric method does not assume that the data follow any particular distribution. In the next section, the Mann-Whitney-Wilcoxon test [Ref. 10:p. 160], sometimes called the Mann-Whitney or Wilcoxon Rank Sum test, will be used to substantiate the results observed by the two sample T-test. This test will not require the assumption of normality of the data.

D. MANN-WHITNEY-WILCOXON TEST

To try to substantiate the results of the two-sample T-test, a less powerful, non-parametric test to compare means was investigated. In the Mann-Whitney-Wilcoxon test, the data are replaced by ranks. Replacing the data by ranks has the effect of moderating the influence of outliers [Ref. 12:p. 403]. In the test, if the null hypothesis is true, then any difference in the outcomes is due to randomization. The test statistic is calculated in the following way. The data consists of two samples $X_1 .. X_m$ and $Y_1 .. Y_n$. Arrange all m + n observations in a single ordered sequence from smallest to largest, but retain the identity (X or Y) of each. Ranks are assigned to the observations with 1 to the smallest and m + n to the largest. Let R_X be the rank sum of the Xs, and R_Y be the rank sum of the Ys. The test statistic T_x is the smaller of the two sums of ranks.

This test does not work well for samples with many ties among the observations. However, if there are only a small number of ties, tied observations are assigned average ranks. The significance levels are not greatly affected by the averaging. Rice [Ref. 12: Table 8] provides a table of critical values (C) which are compared to the test statistic T_x . The null hypothesis is rejected if $T_x \leq C$. If the number of observations are too large for this table then an approximation by the normal distribution is used [Ref. 10:p. 164] .

The Mann-Whitney-Wilcoxon test was used with each set of MOE samples to initially determine if a difference of greater than Δ exists between the vehicles. The Δ values used were those discussed early in this chapter. Should the test fail to reject the null hypothesis, then the test is rerun with a Δ equal to zero. This will determine if there is any improvement shown by the BFVS-A3 and finally the test is used to determine a Δ for which the test will reject, thereby giving an approximation of the improvement, if it exists. The calculations of the test statistic and p-values were done using the S-Plus® function for the Mann-Whitney-Wilcoxon test.

1. MOE 1

With a Δ equal to 0.5, the test failed to reject as did the two sample T-test. To determine if there was any improvement shown by the BFVS-A3, Δ equal to zero was tested. A significant result with a p-value of 0.0196 concurred with the T-test that there was an improvement shown. At Δ equal to 0.300 or equivalently a 300 meter increase to standoff range, the Mann-Whitney-Wilcoxon test was also significant at an α equal to 0.10 level of significance, with a p-value of 0.0962.

2. MOE 2

From the box plot and the two sample T-test results for MOE 2, it is fairly obvious that the test with Δ equal to 0.5 will not reject. The non-parametric test agreed and even at Δ equal to zero this test fails to reject. Again, this is in agreement with the T-test.

3. MOE 3

The test with Δ equal to 3.0 cannot be rejected. This does not agree with the two sample T-test. The non-parametric test is significant at a Δ of 1.0, however not significant

at a Δ of 2.0. Therefore, an increase of between one and two extra kills is suggested by the data and the non-parametric test.

4. MOE 4

The non-parametric test again failed to reject at Δ equal to 20. At Δ equal to zero the non-parametric test rejected and agreed with the T-test that some improvement is shown. At $\Delta = 3$, the p-value is 0.0796, showing that approximately three extra shots were withstood by the BFVS-A3 according to the Mann-Whitney-Wilcoxon test at an α equal to 0.10 level of significance. The p-value at $\Delta = 4$ is 0.1168, and hence the test cannot be rejected at an α equal to 0.10.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Janus provides a useful tool which can be used in the Model-Test-Model concept. During the Pre-test Modeling phase, Janus can be used to simulate the Field Test phase, in order to develop the scenarios which will produce useful data and optimize the use of the resources required for the test. The ability of Janus to predict the results of the field test are dependent on the type of test to be conducted, whether Janus has the functions to accurately model those activities, and on the accuracy of Janus to model the critical issues of the test which are of interest in the analysis. The accuracy of the combat systems database and terrain database are critical to the model predicting reasonable results. In researching this thesis considerable difficulties were experienced in obtaining consistent data in an unclassified form. The scenarios and data analysis conducted are based on the data available at the time, and on assumptions made by the author and experienced Janus users to vary the available BFVS-A2 data to produce BFVS-A3 data. To obtain better results the scenarios and data analysis should be rerun with the more accurate, classified data. The following conclusions are based on the results shown by the analysis of the unclassified data used in this thesis.

Using a two sample T-test, based on assumptions of normality and equal variances, the BFVS-A3 outperformed the BFVS-A2 in the following MOEs: difference between first detection range of defender to attacker; number of kills by BFVs of T-72 and BMP-2 vehicles in a tank heavy company attack; and the number of shots withstood from a tank heavy company attack while in a deliberate defensive position. There was no evidence of increase to maximum lethal engagement range of a BFVS-A3. This result is reasonable since the BFVS-A3 does not have any modification to the weapon system itself, only the acquisition ability. There may have been an expected increase in the engagement range to bring it closer to the maximum range of the weapon. However, there was no evidence of

this shown. This test did not show that the improvements shown were of sufficient magnitude to be significant in a tactical sense, as opposed to a statistical sense.

The lower bound of a 90 % confidence interval for the amount of improvement of the BFVS-A3 over the BFVS-A2 is shown in Table 5.

	Characteristic	**Improvement**
MOE 1	Detection	313 m
MOE 2	Engagement	- 131 m
MOE 3	Lethality	1.2 kills
MOE 4	Survivability	3.7 shots

Table 5. Lower Bound of 90% Confidence Interval for each MOE

Using a Mann-Whitney-Wilcoxon non-parametric test for differences between means, the results of the T-test were supported. The non-parametric test showed a 300 meter improvement in MOE 1, no improvement in MOE 2, between one and two kills improvement in MOE 3, and between 3 and 4 shot improvement in MOE 4.

The assumptions of the two sample T-test did not hold precisely. However, departure from the equal variances assumption is not usually detrimental to the results, and in this case the results have been substantiated by the less powerful non-parametric Mann-Whitney-Wilcoxon test. Therefore, based on the Janus data used these results should reflect the differences between the two vehicle variants.

B. RECOMMENDATIONS

Several recommendations are made as a result of the conduct of the simulation and analysis involved in this thesis. Most importantly, in order to provide any accurate prediction of the outcomes and results of the future field test, the scenarios and data analysis need to be rerun with the more accurate, classified data. Further analysis could also be conducted with the Head-to-Head scenario to provide results which can be

compared to the field test results. In this way, the database and scenarios may be finely tuned during the Post-test Modeling phase of M-T-M to produce the ability to

1. run a large number of simulated battles of the Head-to-Head scenario, to give an indication of variability in the results, not available in the live field test;

2. verify and accredit Janus, in accordance with M-T-M's fifth phase, for use in modeling the BFVS-A2 and BFVS-A3, should accurate results be obtained in the Post-test modeling;

3. run the Force-on-Force scenario and other scenarios with the BFVs against enemy threat vehicles to show the impact on the battle of the new variant of fighting vehicle.

Finally, it must be remembered that this thesis and the Janus simulations only modeled some of the modifications to the BFVS-A2 to produce the BFVS-A3. There are many other characteristics and factors that need to be considered in any overall comparison between the vehicles, and this thesis should be viewed as only one small piece of the process.

APPENDIX A. BLUE SYSTEMS DATABASE

BLUE SYSTEMS GENERAL CHARACTERISTICS

Sys Num	Sys Name	Max Rd Speed (Km/Hr)	Max Visbl (Km)	Wpn Rng (Km)	Sens Hght (m)	Crew Size	Elemt Space (m)	Chem Xmit Fctr	Gra Sym	Host Cap
200	M2A2	61	6.0	3.8	3	3	100	1.00	16	1
201	M2A3	61	6.0	3.8	3	3	100	1.00	17	1

BLUE SYSTEM FUNCTIONAL CHARACTERISTICS

Sys Num	Sys Name	Lsr Dsg	Min Dsp	Eng Typ	Fir Cat	Fly Typ	Log Typ	Mov Typ	Rdr Typ	Smk Dsp	Srv Typ	Swm Typ
200	M2A2	1	3	4	1			2		1		1
201	M2A3	1	3	4	1			2		1		1

BLUE SYSTEM WEIGHTS AND VOLUMES

		Normal Incl Fuel & Ammo		Additional Capacity	
Sys Num	System Name	Weight (lbs)	Volume (CuFt)	Weight (lbs)	Volume (CuFt)
200	M2A2	63425	2200	3000	400
201	M2A3	66450	2200	3000	400

BLUE SYSTEMS DETECTION DATA

		DETECT Dimensions (Meters)				SENSORS				
Sys Num	Sys Name	Lngth	Width	Hght	Prim	Alt	Defil	Popup	BCIS Type	BCIS Func
200	M2A2	6.45	3.20	2.60	29	30	29	1		
201	M2A3	6.45	3.20	2.60	28	30	28	1		

OPTICAL AND THERMAL CONTRAST DATA

		Thermal Contrast	
Sys Num	Optical Contrast	Exposed	Defilade
200	0.35	4.5	1.0
201	0.35	4.5	1.0

SENSOR FIELD of VIEW (FOV) and BAND

Sensor Number	FOV-(Degrees) Narrow	Wide	Narrow-to-Wide Factor	Spectral Band (1,2 = Optical 3,4 = Thermal)
28	3.55	13.33	.26630	4
29	2.00	6.00	.33330	3
30	8.00	12.00	.66660	2

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST

Sensor Number: 28

Pair	Cycles	TMP/CON	Pair	Cycles	TMP/CON
1	.481	.003	11	5.288	.090
2	.961	.004	12	5.769	.147
3	1.442	.005	13	6.250	.237
4	1.923	.006	14	6.731	.400
5	2.404	.011	15	7.212	.512
6	2.885	.016	16	7.692	1.000
7	3.365	.021	17	8.173	2.345
8	3.846	.025	18	8.654	4.563
9	4.327	.041	19	9.135	14.420
10	4.808	.065	20	9.615	100.000

NOTE: TMP/CON data minimum must be associated with PAIR 1, maximum with PAIR 20.

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST

Sensor Number: 29

Pair	Cycles	TMP/CON	Pair	Cycles	TMP/CON
1	.361	.002	11	3.966	.090
2	.721	.003	12	4.327	.137
3	1.082	.005	13	4.688	.217
4	1.442	.007	14	5.048	.355
5	1.803	.010	15	5.409	.607
6	2.164	.014	16	5.769	1.111
7	2.524	.020	17	6.130	2.210
8	2.885	.028	18	6.491	5.053
9	3.245	.040	19	6.851	15.720
10	3.606	.060	20	7.211	100.000

NOTE: TMP/CON data minimum must be associated with PAIR 1, maximum with PAIR 20.

CYCLES per MILLIRADIAN versus TEMPERATURE or CONTRAST

Sensor Number: 30

Pair	Cycles	TMP/CON	Pair	Cycles	TMP/CON
1	.262	.010	11	.676	.450
2	.353	.020	12	.684	.500
3	.449	.050	13	.691	.550
4	.523	.100	14	.697	.600
5	.552	.150	15	.702	.650
6	.586	.200	16	.706	.700
7	.615	.250	17	.714	.800
8	.636	.300	18	.717	.850
9	.653	.350	19	.720	.900
10	.665	.400	20	.725	1.00

NOTE: TMP/CON data minimum must be associated with PAIR 1, maximum with PAIR 20.

WEAPONS / ORDNANCE for BLUE System number 200: M2A2

Wpn/Ord Number Relative (1-15)	Absolute (1-250)	Wpn/Ord Name	Basic Load	Upload Time (Minutes)	Rel Wpn/Ord to use if Ammo Expended (1-15)
1	100	TOW IIB	7	2.0	2
2	101	25MM APDS	500	2.0	1
3	102	25MM HEI	400	2.0	

WEAPONS / ORDNANCE for BLUE System number 201: M2A3

Wpn/Ord Number Relative (1-15)	Absolute (1-250)	Wpn/Ord Name	Basic Load	Upload Time (Minutes)	Rel Wpn/Ord to use if Ammo Expended (1-15)
1	105	TOW IIB	7	2.0	2
2	106	25MM APDS	500	2.0	1
3	107	25MM HEI	400	2.0	

BLUE WEAPON / ROUND CHARACTERISTICS

Wpn Num	Wpn Name	Lay Time (Sec)	Aim Time (Sec)	Reload Time (Sec)	Rnds / Trggr Pull	Trggr Pulls / Reload	Round Speed (Km/Sec)	Min. SSKP
100	A2 TOWIIB	7.3	8.0	38.0	1	2	.171	5
101	25MM APDS	8.3	2.7	300.0	5	50	1.056	5
102	25MM HEI	8.3	2.7	300.0	5	50	.800	5

BLUE WEAPON / ROUND CHARACTERISTICS

Wpn Num	Wpn Name	Lay Time (Sec)	Aim Time (Sec)	Reload Time (Sec)	Rnds / Trggr Pull	Trggr Pulls / Reload	Round Speed (Km/Sec)	Min. SSKP
105	A2 TOWIIB	3.6	4.0	38.0	1	2	.171	5
106	25MM APDS	4.2	1.4	300.0	5	50	1.056	5
107	25MM HEI	4.2	1.4	300.0	5	50	.800	5

BLUE WEAPON / ROUND GUIDANCE DATA

Fire on : 0 = Yes, no restrictions. 1 = Stop, can move before impact
the Move : 3 = Reduce speed to fire. 2 = Stop, only move after impact

Wpn Num	Wpn Name	Guidance Mode	Fire on the Move	On-Board Sensor	Critical Altitude (meters)
100	A2 TOW IIB	1	2		
101	25MM APDS		3		
102	25MM HEI		3		
105	A3 TOW IIB	1	2		
106	25MM APDS		3		
107	25MM HEI		3		

HIT and KILL DATA SET Numbers for BLUE Weapon Number 100: A2 TOW IIB

RED Target Sys Num	RED Target Sys Name	PH Data Set	PK Data Set
201	M2A3	3994	3990
210	T-72	3991	3991
211	BMP-2	3990	3990

HIT and KILL DATA SET Numbers for BLUE Weapon Number 105: A3 TOW IIB

RED Target Sys Num	RED Target Sys Name	PH Data Set	PK Data Set
201	M2A3	3992	3990
210	T-72	3993	3991
211	BMP-2	3992	3990

PROBABILITY of HIT Data Set: 3990

Range(m)--> Posture:	500	1000	2000	3000	3750
SSDF -------------->	0.40000	0.35000	0.30000	0.25000	0.25000
SSDH -------------->	0.35000	0.30000	0.25000	0.20000	0.20000
SSEF -------------->	0.90000	0.85000	0.80000	0.75000	0.75000
SSEH -------------->	0.85000	0.80000	0.75000	0.70000	0.70000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.80000	0.75000	0.70000	0.65000	0.65000
SMEH -------------->	0.75000	0.70000	0.65000	0.60000	0.60000
MSDF -------------->					
MSDH -------------->					
MSEF -------------->					
MSEH -------------->					
MMDF --not used)->					
MMDH --not used)->					
MMEF -------------->					
MMEH -------------->					

NOTE: Defilade data not used when target is a flyer.

PROBABILITY of HIT Data Set: 3991

Range(m)--> Posture:	500	1000	1500	2500	3750
SSDF -------------->	0.70000	0.65000	0.60000	0.55000	0.55000
SSDH -------------->	0.65000	0.60000	0.55000	0.50000	0.50000
SSEF -------------->	0.95000	0.90000	0.85000	0.80000	0.80000
SSEH -------------->	0.90000	0.85000	0.80000	0.75000	0.75000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.85000	0.80000	0.75000	0.70000	0.70000
SMEH -------------->	0.80000	0.75000	0.70000	0.65000	0.65000
MSDF -------------->					
MSDH -------------->					
MSEF -------------->					
MSEH -------------->					
MMDF --not used)->					
MMDH --not used)->					
MMEF -------------->					
MMEH -------------->					

NOTE: Defilade data not used when target is a flyer.

PROBABILITY of HIT Data Set: 3992

Range(m)--> Posture:	500	1000	1500	2500	3750
SSDF -------------->	0.45000	0.40000	0.35000	0.30000	0.30000
SSDH -------------->	0.40000	0.35000	0.30000	0.25000	0.25000
SSEF -------------->	0.95000	0.90000	0.85000	0.80000	0.80000
SSEH -------------->	0.90000	0.85000	0.80000	0.75000	0.75000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.85000	0.80000	0.75000	0.70000	0.70000
SMEH -------------->	0.80000	0.75000	0.70000	0.65000	0.65000
MSDF -------------->					
MSDH -------------->					
MSEF -------------->					
MSEH -------------->					
MMDF --not used)->					
MMDH --not used)->					
MMEF -------------->					
MMEH -------------->					

NOTE: Defilade data not used when target is a flyer.

PROBABILITY of HIT Data Set: 3993

Range(m)--> Posture:	500	1000	1500	2500	3750
SSDF -------------->	0.75000	0.70000	0.65000	0.60000	0.60000
SSDH -------------->	0.70000	0.65000	0.60000	0.55000	0.55000
SSEF -------------->	0.95000	0.95000	0.90000	0.85000	0.85000
SSEH -------------->	0.95000	0.90000	0.85000	0.80000	0.80000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.90000	0.85000	0.80000	0.75000	0.75000
SMEH -------------->	0.85000	0.80000	0.75000	0.70000	0.70000
MSDF -------------->					
MSDH -------------->					
MSEF -------------->					
MSEH -------------->					
MMDF --not used)->					
MMDH --not used)->					
MMEF -------------->					
MMEH -------------->					

NOTE: Defilade data not used when target is a flyer.

PROBABILITY of HIT Data Set: 3994

Range(m)--> Posture:	500	1000	2000	3000	3750
SSDF -------------->	0.35000	0.30000	0.25000	0.20000	0.20000
SSDH -------------->	0.30000	0.25000	0.20000	0.15000	0.15000
SSEF -------------->	0.85000	0.80000	0.75000	0.70000	0.70000
SSEH -------------->	0.80000	0.75000	0.70000	0.65000	0.65000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.75000	0.70000	0.65000	0.60000	0.60000
SMEH -------------->	0.70000	0.65000	0.60000	0.55000	0.55000
MSDF -------------->					
MSDH -------------->					
MSEF -------------->					
MSEH -------------->					
MMDF --not used)->					
MMDH --not used)->					
MMEF -------------->					
MMEH -------------->					

NOTE: Defilade data not used when target is a flyer.

PROBABILITY of KILL Data Set: 3990

Range(m)--> Posture:	500	1000	1500	2500	3750
M/DF -------------->	0.80000	0.80000	0.80000	0.75000	0.50000
M/DH -------------->	0.80000	0.80000	0.80000	0.75000	0.50000
M/EF -------------->	0.80000	0.80000	0.80000	0.75000	0.50000
M/EH -------------->	0.80000	0.80000	0.80000	0.75000	0.50000

PROBABILITY of KILL Data Set: 3991

Range(m)--> Posture:	500	1000	1500	2500	3750
M/DF -------------->	0.32000	0.32000	0.32000	0.32000	0.32000
M/DH -------------->	0.08000	0.08000	0.08000	0.08000	0.08000
M/EF -------------->	0.70000	0.65000	0.60000	0.55000	0.50000
M/EH -------------->	0.25000	0.25000	0.20000	0.10000	0.05000

HIT and KILL DATA SET Numbers for BLUE Weapon Number 101: AP ROUND2

RED Target Sys Num	RED Target Sys Name	PH Data Set	PK Data Set
201	M2A3	3995	3995
210	T-72		
211	BMP-2	3995	3995

HIT and KILL DATA SET Numbers for BLUE Weapon Number 102: LT ARMOR1

RED Target Sys Num	RED Target Sys Name	PH Data Set	PK Data Set
201	M2A3	3996	3995
210	T-72		
211	BMP-2	3996	3995

HIT and KILL DATA SET Numbers for BLUE Weapon Number 106: AP ROUND2

RED Target Sys Num	RED Target Sys Name	PH Data Set	PK Data Set
201	M2A2	3995	3995
210	T-72		
211	BMP-2	3995	3995

HIT and KILL DATA SET Numbers for BLUE Weapon Number 107: LT ARMOR1

RED Target Sys Num	RED Target Sys Name	PH Data Set	PK Data Set
201	M2A2	3996	3995
210	T-72		
211	BMP-2	3996	3995

PROBABILITY of HIT Data Set: 3995

Range(m)--> Posture:		400	800	1600	2800
SSDF -------------->	0.90000	0.80000	0.40000	0.20000	
SSDH -------------->	0.90000	0.80000	0.40000	0.20000	
SSEF -------------->	0.99000	0.90000	0.50000	0.30000	0.10000
SSEH -------------->	0.99000	0.90000	0.50000	0.30000	0.10000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.90000	0.80000	0.40000	0.20000	
SMEH -------------->	0.90000	0.80000	0.40000	0.20000	
MSDF -------------->	0.70000	0.60000	0.20000		
MSDH -------------->	0.70000	0.60000	0.20000		
MSEF -------------->	0.90000	0.80000	0.40000	0.20000	
MSEH -------------->	0.90000	0.80000	0.40000	0.20000	
MMDF --not used)->					
MMDH --not used)->					
MMEF -------------->	0.70000	0.60000	0.20000		
MMEH -------------->	0.70000	0.60000	0.20000		

NOTE: Defilade data not used when target is a flyer.

PROBABILITY of HIT Data Set: 3996

Range(m)--> Posture:		400	800	1600	2800
SSDF -------------->	0.69000	0.69000	0.65000	0.39000	0.20000
SSDH -------------->	0.68000	0.68000	0.65000	0.38000	0.19000
SSEF -------------->	0.99000	0.99000	0.90000	0.70000	0.50000
SSEH -------------->	0.99000	0.99000	0.85000	0.65000	0.45000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.99000	0.90000	0.80000	0.60000	0.40000
SMEH -------------->	0.90000	0.85000	0.75000	0.55000	0.35000
MSDF -------------->	0.60000	0.60000	0.55000	0.30000	0.06000
MSDH -------------->	0.55000	0.55000	0.50000	0.25000	0.05000
MSEF -------------->	0.99000	0.90000	0.80000	0.60000	0.40000
MSEH -------------->	0.90000	0.85000	0.75000	0.55000	0.35000
MMDF --not used)->					
MMDH --not used)->					
MMEF -------------->	0.90000	0.80000	0.70000	0.50000	0.30000
MMEH -------------->	0.80000	0.70000	0.60000	0.40000	0.20000

NOTE: Defilade data not used when target is a flyer.

PROBABILITY of KILL Data Set: 3995

Range(m)-->		400	800	1600	2800
Posture:					
M/DF -------------->	0.55000	0.55000	0.50000	0.40000	0.20000
M/DH -------------->	0.45000	0.45000	0.40000	0.30000	0.10000
M/EF -------------->	0.85000	0.85000	0.80000	0.70000	0.50000
M/EH -------------->	0.75000	0.75000	0.70000	0.60000	0.40000

APPENDIX B. ENEMY SYSTEMS DATABASE

RED SYSTEMS GENERAL CHARACTERISTICS

Sys Num	Sys Name	Max Rd Speed (Km/Hr)	Max Visbl (Km)	Wpn Rng (Km)	Sens Hght (m)	Crew Size	Elemt Space (m)	Chem Xmit Fctr	Gra Sym	Host Cap
211	BMP-2	65	6.0	4.0	2	4	40	1.00	102	1
210	T-72	65	6.0	4.0	2	3	40	1.00	98	1

RED SYSTEM FUNCTIONAL CHARACTERISTICS

Sys Num	Sys Name	Lsr Dsg	Min Dsp	Eng Typ	Fir Cat	Fly Typ	Log Typ	Mov Typ	Rdr Typ	Smk Dsp	Srv Typ	Swm Typ
211	BMP-2	1		5	1			2		2	1	1
210	T-72			3	1			2		3	1	

RED SYSTEM WEIGHTS AND VOLUMES

Sys Num	System Name	Normal Incl Fuel & Ammo Weight (lbs)	Normal Incl Fuel & Ammo Volume (CuFt)	Additional Capacity Weight (lbs)	Additional Capacity Volume (CuFt)
211	BMP-2	32000		3000	400
210	T-72	92000		3000	400

RED SYSTEMS DETECTION DATA

Sys Num	Sys Name	DETEC Dimensions (Meters) Lngth	Width	Hght	SENSORS Prim	Altr	Defil	Popup	BCIS Type	BCIS Type
211	BMP-2	6.82	3.13	2.08	21	36	21	1		
210	T-72	7.20	3.46	2.30	11	8	11	1		

OPTICAL AND THERMAL CONTRAST DATA

System Type	System Name	OPTICAL CONTRAST	THERMAL CONTRAST Exposed	Defilade
211	BMP-2	0.35	4.0	0.5
210	T-72	0.35	4.0	0.5

SENSOR FIELD of VIEW (FOV) and BAND

Sensor Number	FOV-(Degrees) Narrow	Wide	Narrow-to-Wide Factor	Spectral Band (1,2 = Optical 3,4 = Thermal)
8	6.50			1
11	6.00			1
21	15.00			1
36	8.00			2

WEAPONS / ORDNANCE for RED System number 211: BMP-2

Wpn/Ord Relative (1-15)	Number Absolute (1-250)	Wpn/Ord Name	Basic Load	Upload Time (Minutes)	Rel Wpn/Ord to use if Ammo Expended (1-15)
1	397	MISSILE-6	5	2.0	3
2	339	LT ARMR 9	500	2.0	4
3	390	AP RND 1	3000	2.0	1
4	338	LT ARMR 10	500	2.0	2

WEAPONS / ORDNANCE for RED System number 210: T-72

Wpn/Ord Relative (1-15)	Number Absolute (1-250)	Wpn/Ord Name	Basic Load	Upload Time (Minutes)	Rel Wpn/Ord to use if Ammo Expended (1-15)
1	395	TANK RND 1	8	2.0	2
2	394	TANK RND 2	`26	2.0	1
3	390	AP RND 1	3000	2.0	4
4	368	LT ARMR - 1	1000	2.0	3

RED WEAPON / ROUND CHARACTERISTICS

Wpn Num	Wpn Name	Lay Time (Sec)	Aim Time (Sec)	Reload Time (Sec)	Rnds / Trggr Pull	Trggr Pulls / Reload	Round Speed (Km/Sec)	Min. SSKP
338	LT ARMR 10	8.3	2.7	20.0	5	20	.613	5
339	LT ARMR 9	8.3	2.7	20.0	5	20	1.056	5
368	LT ARMR 1	8.3	2.7	10.0	20	10	.470	5
390	AP RND 1	8.3	4.5	10.0	15	50	.8	5
394	TANK RND 2	10.1	5.7	7.0	1	1	1.555	5
395	TANK RND 1	10.1	5.7	7.0	1	1	.515	5
397	MISSILE-6	10.0	7.0	12.0	1	1	.1	5

RED WEAPON / ROUND GUIDANCE DATA

Fire on : 0 = Yes, no restrictions. 1 = Stop, can move before impact
the Move : 3 = Reduce speed to fire. 2 = Stop, only move after impact

Wpn Num	Wpn Name	Guidance Mode	Fire on the Move	On-Board Sensor	Critical Altitude (meters)
394			3		
395			3		
397			1		

HIT and KILL DATA SET Numbers for RED Weapon Number 397: MISSILE-6

BLUE Target Sys Num	BLUE Target Sys Name	PH Data Set	PK Data Set
210	M2A2	3980	3980
211	M2A3	3981	3980

HIT and KILL DATA SET Numbers for RED Weapon Number 339: LT ARMR 9

BLUE Target Sys Num	BLUE Target Sys Name	PH Data Set	PK Data Set
210	M2A2	3982	3982
211	M2A3	3982	3982

HIT and KILL DATA SET Numbers for RED Weapon Number 394: TANK RND 2

BLUE Target Sys Num	BLUE Target Sys Name	PH Data Set	PK Data Set
210	M2A2	3984	3984
211	M2A3	3984	3984

HIT and KILL DATA SET Numbers for RED Weapon Number 395: TANK RND 1

BLUE Target Sys Num	BLUE Target Sys Name	PH Data Set	PK Data Set
210	M2A2	3984	3984
211	M2A3	3984	3984

PROBABILITY of HIT Data Set: 3980

Range(m)--> Posture:		1000	1500	2500	4000
SSDF -------------->	0.66000	0.63000	0.62000	0.61000	0.60000
SSDH -------------->	0.61000	0.59000	0.58000	0.57000	0.56000
SSEF -------------->	0.88000	0.86000	0.84000	0.83000	0.82000
SSEH -------------->	0.83000	0.81000	0.80000	0.79000	0.78000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.79000	0.77000	0.76000	0.75000	0.74000
SMEH -------------->	0.75000	0.73000	0.72000	0.71000	0.70000
MSDF -------------->	0.59000	0.55000	0.52000	0.51000	0.50000
MSDH -------------->	0.55000	0.53000	0.48000	0.47000	0.46000
MSEF -------------->	0.70000	0.68000	0.68000	0.67000	0.66000
MSEH -------------->	0.67000	0.65000	0.64000	0.63000	0.62000
MMDF --not used)--->					
MMDH --not used)--->					
MMEF -------------->	0.61000	0.60000	0.59000	0.58000	0.58000
MMEH -------------->	0.58000	0.57000	0.56000	0.55000	0.54000

PROBABILITY of HIT Data Set: 3981

Range(m)--> Posture:		1000	1500	2500	4000
SSDF -------------->	0.61000	0.58000	0.57000	0.56000	0.55000
SSDH -------------->	0.56000	0.54000	0.53000	0.52000	0.51000
SSEF -------------->	0.83000	0.81000	0.79000	0.78000	0.77000
SSEH -------------->	0.78000	0.76000	0.75000	0.74000	0.73000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.74000	0.72000	0.71000	0.70000	0.69000
SMEH -------------->	0.70000	0.68000	0.67000	0.66000	0.65000
MSDF -------------->	0.54000	0.50000	0.47000	0.46000	0.45000
MSDH -------------->	0.50000	0.48000	0.43000	0.42000	0.41000
MSEF -------------->	0.65000	0.63000	0.63000	0.62000	0.61000
MSEH -------------->	0.62000	0.60000	0.59000	0.58000	0.57000
MMDF --not used)--->					
MMDH --not used)--->					
MMEF -------------->	0.56000	0.55000	0.54000	0.53000	0.53000
MMEH -------------->	0.53000	0.52000	0.51000	0.50000	0.49000

PROBABILITY of HIT Data Set: 3982

Range(m)--> Posture:		1000	1500	2000	3000
SSDF -------------->	0.34000	0.26000	0.19000	0.13000	0.09000
SSDH -------------->	0.30000	0.23000	0.16000	0.10000	0.06000
SSEF -------------->	0.46000	0.37000	0.29000	0.20000	0.14000
SSEH -------------->	0.41000	0.31000	0.24000	0.17000	0.11000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.41000	0.30000	0.26000	0.18000	0.13000
SMEH -------------->	0.37000	0.28000	0.22000	0.15000	0.10000
MSDF -------------->	0.31000	0.23000	0.17000	0.12000	0.08000
MSDH -------------->	0.27000	0.21000	0.14000	0.09000	0.05000
MSEF -------------->	0.37000	0.30000	0.23000	0.16000	0.11000
MSEH -------------->	0.33000	0.25000	0.19000	0.14000	0.09000
MMDF --not used)--->					
MMDH --not used)--->					
MMEF -------------->	0.32000	0.26000	0.20000	0.14000	0.10000
MMEH -------------->	0.29000	0.22000	0.17000	0.12000	0.08000

PROBABILITY of HIT Data Set: 3984

Range(m)--> Posture:		500	1000	2000	2400
SSDF -------------->	0.99000	0.94000	0.57000	0.27000	0.14000
SSDH -------------->	0.99000	0.94000	0.54000	0.25000	0.13000
SSEF -------------->	0.99000	0.99000	0.95000	0.83000	0.60000
SSEH -------------->	0.99000	0.99000	0.90000	0.75000	0.53000
SMDF --(not used)-->					
SMDH --(not used)-->					
SMEF -------------->	0.99000	0.99000	0.90000	0.75000	0.32000
SMEH -------------->	0.99000	0.99000	0.85000	0.64000	0.25000
MSDF -------------->	0.89000	0.81000	0.40000	0.15000	0.07000
MSDH -------------->	0.89000	0.80000	0.38000	0.14000	0.07000
MSEF -------------->	0.89000	0.89000	0.90000	0.63000	0.30000
MSEH -------------->	0.89000	0.89000	0.80000	0.57000	0.30000
MMDF --not used)--->					
MMDH --not used)--->					
MMEF -------------->	0.89000	0.89000	0.85000	0.55000	0.24000
MMEH -------------->	0.89000	0.89000	0.75000	0.48000	0.15000

PROBABILITY of KILL Data Set: 3980

Range(m)--> Posture:		1000	1500	2500	4000
M/ DF ------------->	0.70000	0.70000	0.60000	0.35000	0.10000
M/ DH ------------>	0.70000	0.70000	0.60000	0.30000	0.05000
M/ EF ------------->	0.70000	0.70000	0.70000	0.50000	0.40000
M/ EH ------------->	0.70000	0.70000	0.70000	0.45000	0.35000

PROBABILITY of KILL Data Set: 3982

Range(m)--> Posture:		1000	1500	2000	3000
M/ DF ------------->	0.70000	0.60000	0.40000	0.10000	
M/ DH ------------>	0.70000	0.60000	0.40000	0.10000	
M/ EF ------------->	0.70000	0.70000	0.60000	0.20000	
M/ EH ------------->	0.60000	0.60000	0.50000	0.10000	

PROBABILITY of KILL Data Set: 3984

Range(m)--> Posture:		500	1000	2000	2400
M/ DF ------------->	0.88000	0.87000	0.80000	0.73000	0.69000
M/ DH ------------>	0.84000	0.84000	0.75000	0.70000	0.65000
M/ EF ------------->	0.94000	0.93000	0.85000	0.80000	0.75000
M/ EH ------------->	0.85000	0.85000	0.80000	0.75000	0.70000

APPENDIX C. SCENARIOS

This appendix shows the Janus screens of the defending and attacking forces in the Head-to-Head scenario and the Force-on-Force scenario. The terrain chosen for the Head-to-Head scenario is shown in Figures 17 and 18. Figure 17 shows the Bradley platoon hasty defensive position and the field of view of one of the vehicles. The field of view shows direction and extent of the systems vision, together with its engagement area. The inner dotted curve is the maximum engagement range, and the outer curve is the maximum visual range. The dotted fan shows the areas the system can see, and breaks in the fan indicate areas the system cannot see.

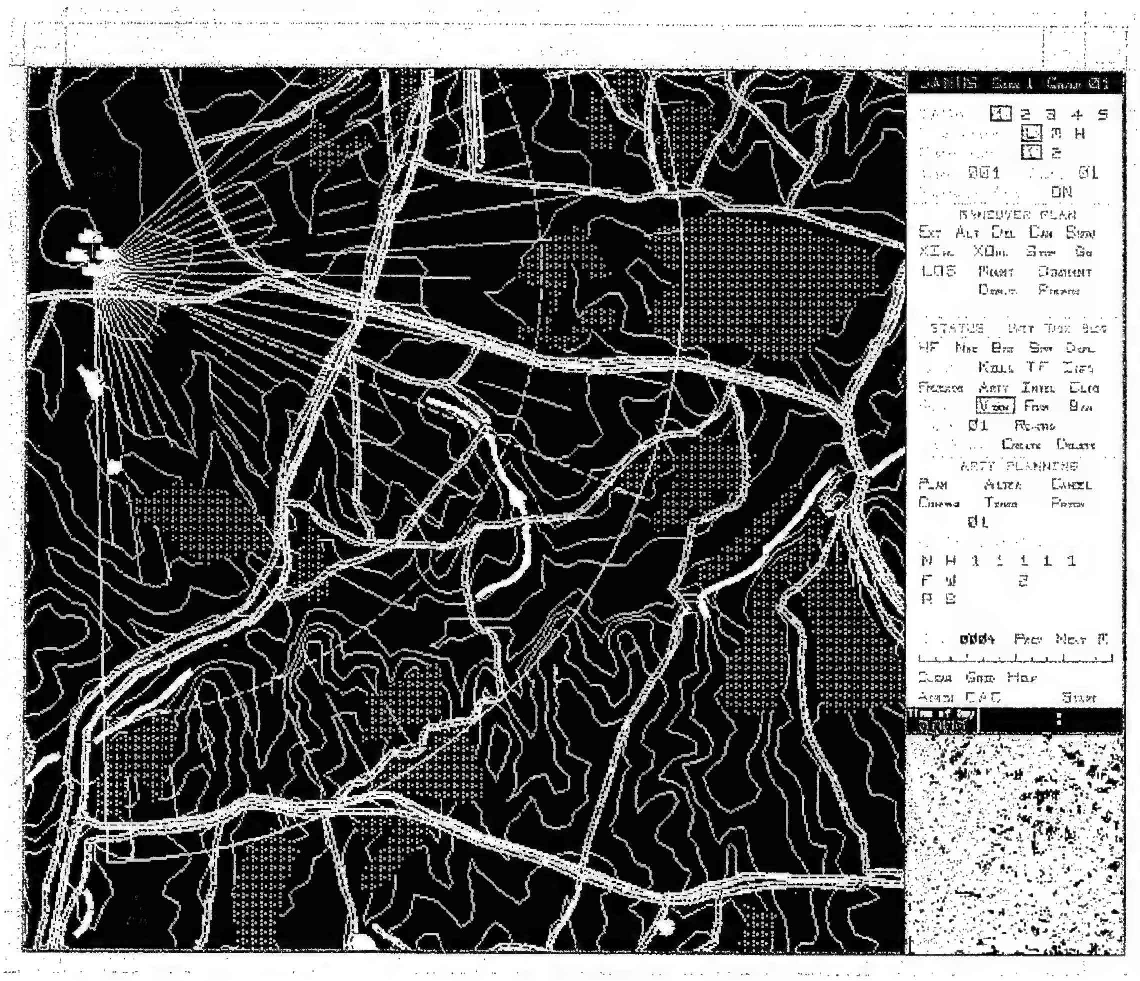


Figure 17. The Janus screen showing the Head-to-Head scenario hasty defensive position and the field of view from one of the vehicles

Figure 18 shows the approach used by the attacking force in the Head-to-Head scenario. The figure shows the Janus screen from scenario 120 with the defending BFV position drawn over the screen capture. The figure also shows the "stop nodes", represented by inverted triangles, used on each bound along the preplanned route, to allow the controller to replicate bounding overwatch method of movement. The vehicles move as sections of two vehicles from bound to bound. The first section to move is the northernmost section of two vehicles. The sections then move in turn until either all vehicles in the attacking force or all vehicles in the defending force are destroyed.

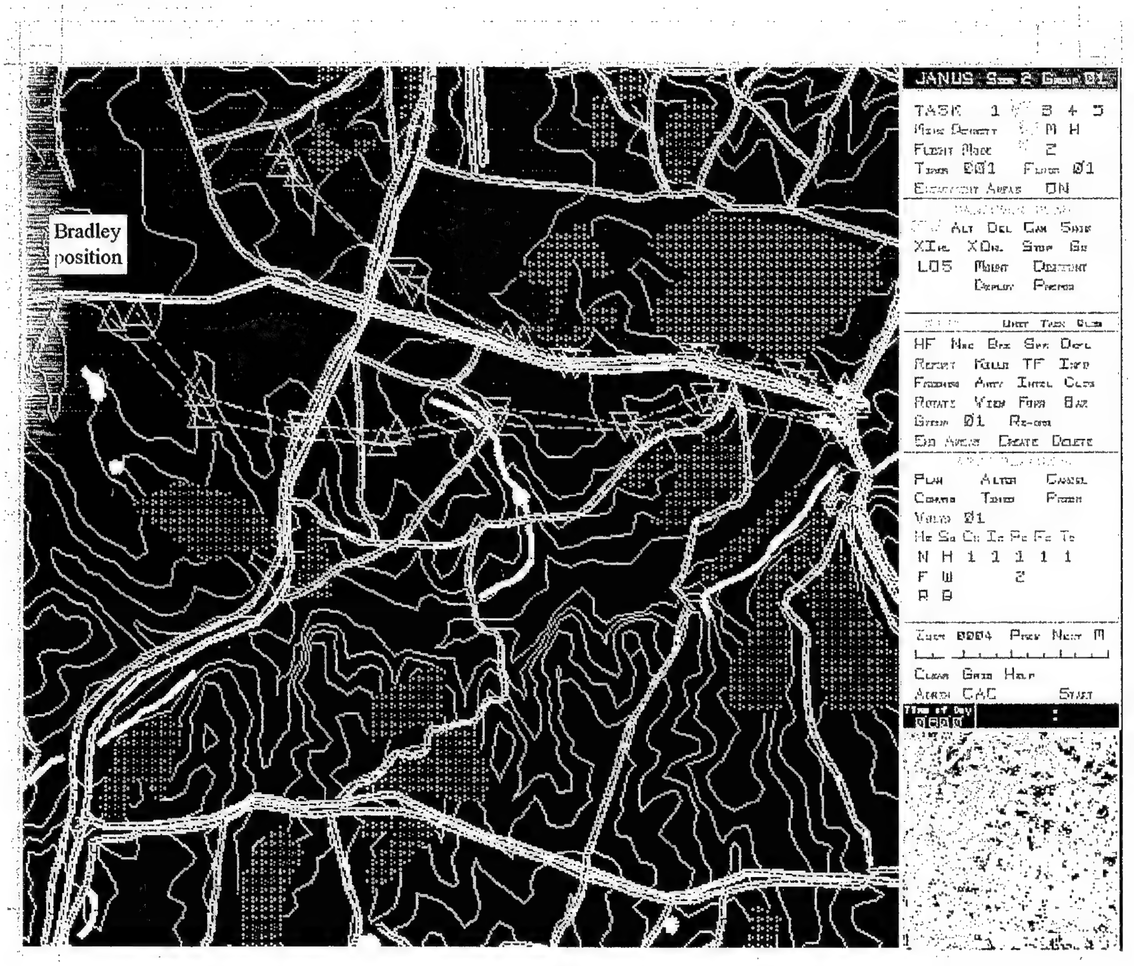


Figure 18. Janus screen showing the routes and bounds used by the attacking force in scenarios 120 and 150

Figure 19 is a similar Janus screen for the Force-on-Force scenario showing the defending Bradley platoon position. The BFVs are in a deliberate defensive position. In Janus, the prepared defensive position for each vehicle is represented by a small circle. As shown in the figure, the Bradley Fighting Vehicle symbol is then placed over the prepared position to represent the vehicle fighting from in a prepared defensive position. Again, the field of view of one of the Bradleys is shown by the field of view fan, and the maximum engagement range and visual ranges are shown. The positions for the vehicles were chosen to give the most effective fields of vision in the direction of enemy approach.

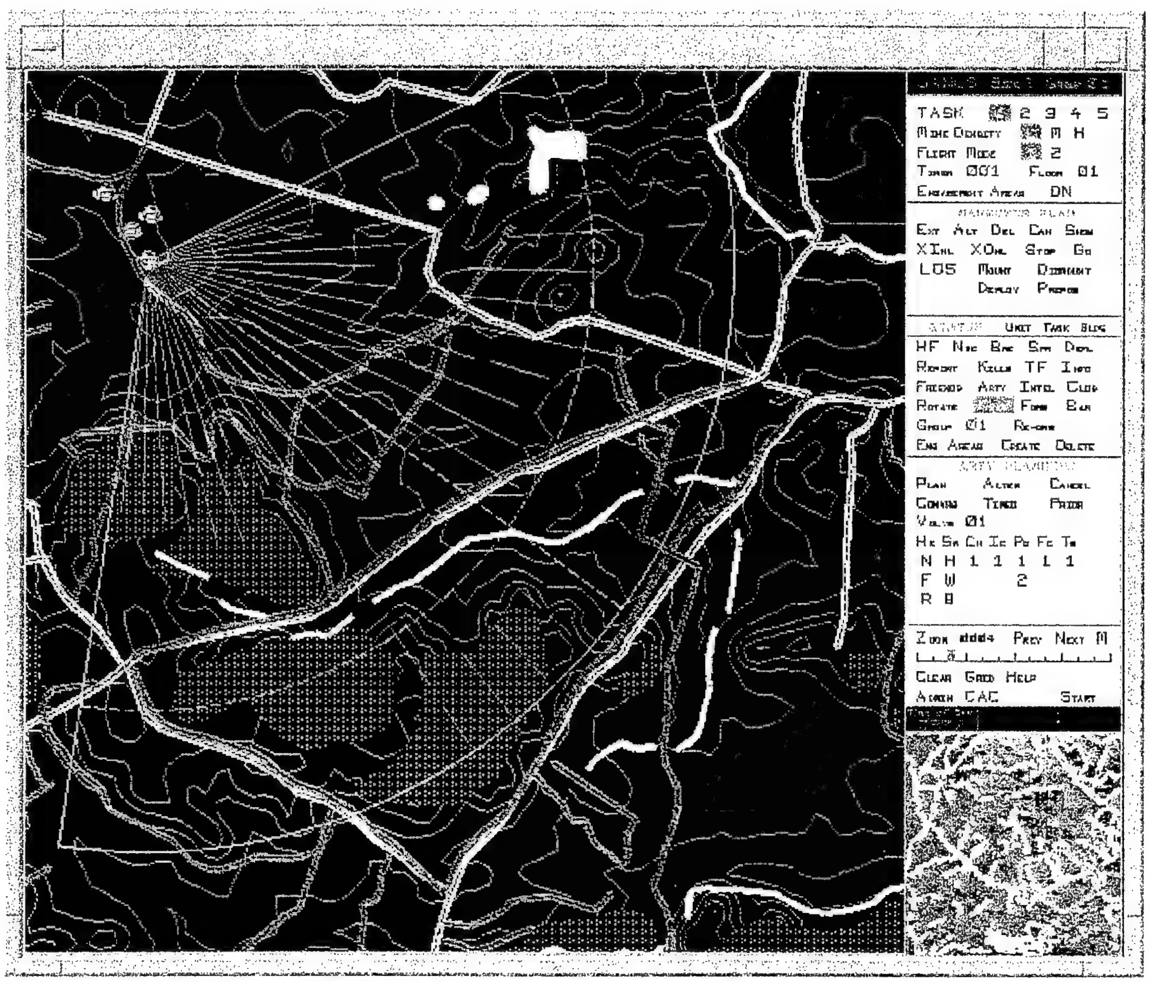


Figure 19. Janus screen showing formation of Defending force in the Force-on-Force scenario

Figure 20 shows the formation of the attacking force in the Force-on-force scenario. The Soviet style tank heavy company consists of four T-72 tanks leading, followed by three platoons each of three BMP-2 fighting vehicles, and the Company Commander and Machine Gun platoon of two BMP-2 vehicles to the rear.

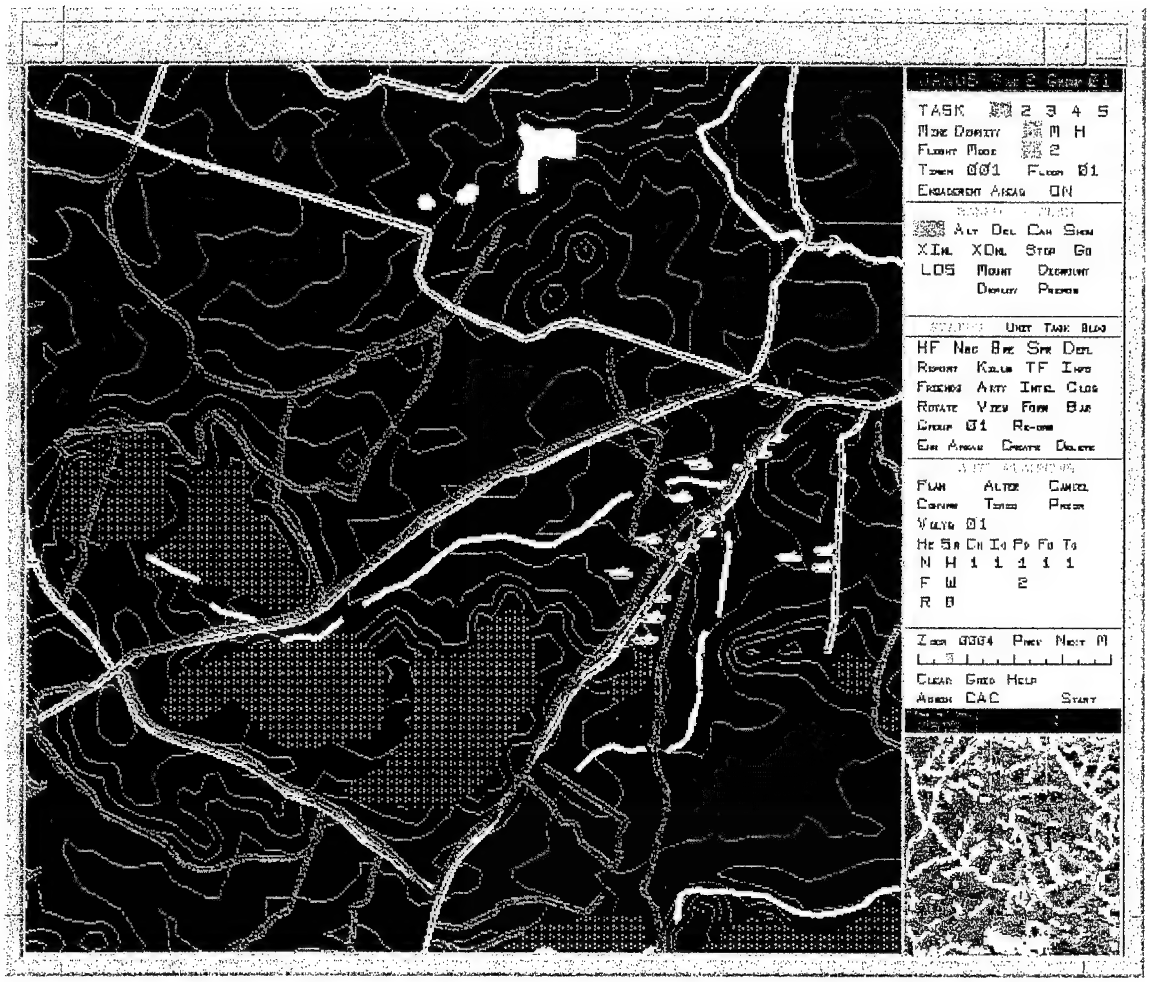


Figure 20. The attacking tank heavy company formation in the Force-on-Force scenario

APPENDIX D. EXAMPLE POSTPROCESSOR FILE

This appendix shows relevant parts of the postprocessor files produced by Janus, version 6.0. The file includes the execution parameters, Direct Fire Report, Coroner's Report, and Detection Report. A similar report is generated for each run of each scenario. As the number of weapons and vehicles in a scenario increase, obviously the number of detections increase. As such, these postprocessor files can become very lengthy.

The screen parameters are entered in the Janus execution screens prior to the initialization of a run. These parameters control conditions that will apply to the simulation. Some will not impact the battle, but will control the display the user sees. Whereas, other parameters, such as suppression time will impact on the battle. The Direct Fire Report shows the game time, firer details, and weapon details for each shot fired during the game. These entries are self explanatory except for "STAT" which refers to the firer-target status and "SSKP" which is the single shot kill probability. The firer-target status is a four letter code for firer being stationary (S) or moving (M), the target being stationary (S) or moving (M), the target in defilade (D) or exposed (E) and target aspect being head-on (H) or flank-on (F). The Coroner's Report shows the victim and killer type and location, weapon and range for each shot which results in a kill. The Detection Report shows the detector and detected system's type and status, and range at which the detection occurs, for all detection during the game.

Run 1 of Scenario Number 120 - A2DEF-A3ATK

---------- SCREEN 1 PARAMETERS ----------

RANDOM NUM INITIALIZE	RANDOM # SEED	TIME OF DAY	UPDATE (SEC.)	TARGET CY(SEC)	DETECT CY(SEC)	DEFILADE TIME(MIN)	ARTY DUST	TERRAIN FILE #	OUTER-MOST MAP FILE	SYMBOL FILE #
Random	31	0800	2.00	20	3.0	.5	Yes	981	981	1

---------- SCREEN 2 PARAMETERS ----------

---------- SCREEN 3 PARAMETERS ----------

---------- SCREEN 4 PARAMETERS ----------

	Side 1	Side 2	Side 3	Side 4	Side 5	Side 6
Group Speed (km/hr)	40.	40.	0.	0.	0.	0.
Fractricide On	No	No	No	No	No	No
Firing Criteria	Recog	Recog	Recog	Recog	Recog	Recog

---------- SUPPRESSION DATA ----------			---- SUPPRESSION TIMES (SEC) ----		
DF Prob Coefficient	Arty Rad Factor	Arty PK Threshold	DF Soldier	DF Other	Arty
1.00	5.00	.001	12	10	20

---------- SCREEN 5 PARAMETERS ----------

Run 1 of Scenario Number 120 - A2DEF-A3ATK

GAME	------------FIRER-----------				----------TARGET-----------									
TIME	UNIT	SIDE	NAME	SPEED	UNIT	SIDE	NAME	SPEED	STAT	NFIR	SSKP	RANGE	WEAPON	T-SUPR
15:21	3	1	M2A2	.0	4	2	M2A3	20.0	SMEH	1	.28	3.725	A2 TOWIIB	10
17:42	4	1	M2A2	.0	2	2	M2A3	20.0	SMEH	1	.28	3.693	A2 TOWIIB	10
18:12	4	1	M2A2	.0	1	2	M2A3	20.0	SMEH	1	.28	3.679	A2 TOWIIB	10
19:54	1	1	M2A2	.0	2	2	M2A3	20.0	SMEH	1	.36	2.949	A2 TOWIIB	10
19:54	2	1	M2A2	.0	2	2	M2A3	20.0	SMEH	1	.39	2.790	A2 TOWIIB	10
20:07	2	2	M2A3	20.0	1	1	M2A2	.0	SSDH	1	.17	2.865	A3 TOWIIB	10
20:14	4	1	M2A2	.0	2	2	M2A3	.0	SSEH	1	.43	2.952	A2 TOWIIB	
20:15	3	1	M2A2	.0	2	2	M2A3	.0	SSEH	1	.45	2.803	A2 TOWIIB	
20:16	1	2	M2A3	20.0	2	1	M2A2	.0	SSDH	1	.18	2.748	A3 TOWIIB	10
20:19	2	1	M2A2	.0	2	2	M2A3	.0	SSEH	1	.47	2.708	A2 TOWIIB	
20:20	1	1	M2A2	.0	1	2	M2A3	.0	SSEH	1	.44	2.907	A2 TOWIIB	
20:28	2	2	M2A3	.0	1	1	M2A2	.0	SSDH	1	.17	2.865	A3 TOWIIB	10
20:36	1	2	M2A3	.0	2	1	M2A2	.0	SSDH	1	.18	2.748	A3 TOWIIB	10
20:46	4	1	M2A2	.0	1	2	M2A3	.0	SSEH	1	.42	2.992	A2 TOWIIB	
23:57	4	1	M2A2	.0	4	2	M2A3	20.0	SMEH	1	.36	2.993	A2 TOWIIB	10
24:23	4	1	M2A2	.0	3	2	M2A3	20.0	SMEH	1	.37	2.890	A2 TOWIIB	10
24:45	3	1	M2A2	.0	3	2	M2A3	20.0	SMEH	1	.42	2.601	A2 TOWIIB	
24:49	4	2	M2A3	20.0	2	1	M2A2	.0	SSDH	1	.19	2.528	A3 TOWIIB	10
24:50	3	2	M2A3	20.0	2	1	M2A2	.0	SSDH	1	.18	2.570	A3 TOWIIB	10
25:08	4	2	M2A3	.0	2	1	M2A2	.0	SSDH	1	.19	2.528	A3 TOWIIB	10
25:16	3	1	M2A2	.0	4	2	M2A3	.0	SSEH	1	.50	2.540	A2 TOWIIB	10
25:26	4	1	M2A2	.0	4	2	M2A3	.0	SSEH	1	.47	2.724	A2 TOWIIB	10
25:30	1	1	M2A2	.0	4	2	M2A3	.0	SSEF	1	.50	2.723	A2 TOWIIB	

Run 1 of Scenario Number 120 - A2DEF-A3ATK

GAME	KILL	VICTIM						KILLER						
TIME	TYPE	UNIT	SIDE	NAME	X	Y	LOSS	UNIT	SIDE	NAME	X	Y	RANGE	PRJ/WPN/MF
20:31	DF	2	2	M2A3	9.8	52.2	1	4	1	M2A2	6.9	52.5	2.95	A2 TOWIIB
21:04	DF	1	2	M2A3	9.9	52.1	1	4	1	M2A2	6.9	52.5	2.99	A2 TOWIIB
25:01	DF	3	2	M2A3	9.1	50.9	1	3	1	M2A2	7.0	52.3	2.57	A2 TOWIIB
25:46	DF	4	2	M2A3	9.2	51.0	1	1	1	M2A2	7.0	52.6	2.72	A2 TOWIIB

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Run 1 of Scenario Number 120 - A2DEF-A3ATK

SIDE 1 detecting SIDE 2

GAME	DETECTOR					DETECTED				
TIME	UNIT	SIDE	NAME	SENSOR	STATUS	UNIT	SIDE	NAME	STATUS	RANGE
10:43	4	1	M2A2	0	STATIONRY, DEFIL	2	2	M2A3	MOVING, EXPOSED	4.835
11:31	2	1	M2A2	0	STATIONRY, DEFIL	2	2	M2A3	MOVING, EXPOSED	4.332
12:04	4	1	M2A2	0	STATIONRY, DEFIL	1	2	M2A3	MOVING, EXPOSED	4.407
12:07	1	1	M2A2	0	STATIONRY, DEFIL	1	2	M2A3	MOVING, EXPOSED	4.335
12:16	1	1	M2A2	0	STATIONRY, DEFIL	2	2	M2A3	MOVING, EXPOSED	4.267
12:19	3	1	M2A2	0	STATIONRY, DEFIL	1	2	M2A3	MOVING, EXPOSED	4.188
14:07	3	1	M2A2	0	STATIONRY, DEFIL	4	2	M2A3	MOVING, EXPOSED	4.138
14:07	4	1	M2A2	0	STATIONRY, DEFIL	3	2	M2A3	MOVING, EXPOSED	4.481
14:22	4	1	M2A2	0	STATIONRY, DEFIL	4	2	M2A3	MOVING, EXPOSED	4.220
14:43	2	1	M2A2	0	STATIONRY, DEFIL	3	2	M2A3	MOVING, EXPOSED	4.052
15:13	1	1	M2A2	0	STATIONRY, DEFIL	3	2	M2A3	MOVING, EXPOSED	4.092
17:04	4	1	M2A2	0	STATIONRY, DEFIL	2	2	M2A3	MOVING, EXPOSED	3.931
17:52	4	1	M2A2	0	STATIONRY, DEFIL	1	2	M2A3	MOVING, EXPOSED	3.766
19:46	1	1	M2A2	0	STATIONRY, DEFIL	2	2	M2A3	MOVING, EXPOSED	2.977
19:46	2	1	M2A2	0	STATIONRY, DEFIL	2	2	M2A3	MOVING, EXPOSED	2.818
20:07	3	1	M2A2	0	STATIONRY, DEFIL	2	2	M2A3	STATIONRY, EXPOSD	2.803
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
24:49	2	1	M2A2	0	STATIONRY, DEFIL	4	2	M2A3	STATIONRY, EXPOSD	2.528
24:49	3	1	M2A2	0	STATIONRY, DEFIL	4	2	M2A3	STATIONRY, EXPOSD	2.540
25:22	1	1	M2A2	0	STATIONRY, DEFIL	4	2	M2A3	STATIONRY, EXPOSD	2.723

Run 1 of Scenario Number 120 - A2DEF-A3ATK

SIDE 2 detecting SIDE 1

GAME	DETECTOR					DETECTED				
TIME	UNIT	SIDE	NAME	SENSOR	STATUS	UNIT	SIDE	NAME	STATUS	RANGE
20:03	2	2	M2A3	29	MOVING, EXPOSED	1	1	M2A2	STATIONRY, DEFIL	2.893
20:12	1	2	M2A3	29	MOVING, EXPOSED	2	1	M2A2	STATIONRY, DEFIL	2.777
20:18	2	2	M2A3	29	STATIONRY, EXPOSD	3	1	M2A2	STATIONRY, DEFIL	2.803
20:18	2	2	M2A3	29	STATIONRY, EXPOSD	4	1	M2A2	STATIONRY, DEFIL	2.952
24:42	3	2	M2A3	29	MOVING, EXPOSED	2	1	M2A2	STATIONRY, DEFIL	2.620
24:42	3	2	M2A3	29	MOVING, EXPOSED	4	1	M2A2	STATIONRY, DEFIL	2.811
24:45	4	2	M2A3	29	MOVING, EXPOSED	2	1	M2A2	STATIONRY, DEFIL	2.554
24:51	3	2	M2A3	29	STATIONRY, EXPOSD	3	1	M2A2	STATIONRY, DEFIL	2.575
24:51	4	2	M2A3	29	STATIONRY, EXPOSD	3	1	M2A2	STATIONRY, DEFIL	2.540

APPENDIX E. RAW DATA

This appendix shows the raw data that was used in the analysis. This data was drawn from the Direct Fire Reports, Coroner's Reports, and Detection Reports contained in the postprocessor file from each run conducted.

	A2 DEF - A3 ATK Scenario			A3 DEF - A2 ATK Scenario			A2 DEF - Coy Atk Scenario			A3 DEF - Coy Atk Scenario		
Run #	Defender Det range	Attacker Det range	MOE1A2	Defender Det range	Attacker Det range	MOE1A3	Max Eng Range	# En killed	# En shots fired	Max Eng Range	# En killed	# En shots fired
1	4.835	2.952	1.883	5.327	3.025	2.302	3.66	7	71	3.24	12	68
2	4.904	3.758	1.146	5.359	3.758	1.601	3.52	7	39	3.39	7	41
3	4.805	2.893	1.912	5.439	2.821	2.618	3.70	2	46	3.26	5	47
4	4.663	2.503	2.160	5.463	3.758	1.705	3.38	7	75	3.18	5	87
5	4.397	4.144	0.253	5.439	3.758	1.681	3.65	4	36	3.51	4	79
6	4.582	3.074	1.508	5.285	0.000	5.285	3.36	5	33	3.38	13	69
7	4.962	2.843	2.119	5.463	2.831	2.632	3.26	2	47	3.26	5	65
8	4.660	2.821	1.839	5.463	2.818	2.645	3.56	10	56	3.47	11	68
9	4.524	2.821	1.703	5.439	0.000	5.439	3.36	3	48	3.65	4	62
10	4.663	4.572	0.091	5.378	3.938	1.440	3.71	3	25	3.71	2	59
11	4.885	3.839	1.046	5.359	0.000	5.359	2.65	1	40	3.74	5	59
12	4.267	5.428	-1.161	5.378	2.831	2.547	3.66	4	61	3.55	3	20
13	4.267	2.898	1.369	5.359	3.563	1.796	3.39	3	24	3.50	5	69
14	4.413	0.000	4.413	5.327	2.815	2.512	3.60	3	47	3.56	4	41
15	4.856	3.758	1.098	5.513	3.693	1.820	3.62	4	75	3.46	5	58
16	4.498	3.174	1.324	4.944	3.758	1.186	3.36	4	56	3.12	11	100
17	4.806	2.733	2.073	4.914	4.103	0.811	3.00	1	21	3.62	8	28
18	4.167	4.304	-0.137	5.439	3.758	1.681	3.40	1	66	3.36	5	32
19	4.305	3.020	1.285	5.359	2.123	3.236	3.68	4	38	3.44	4	52
20	4.663	2.673	1.990	5.215	3.758	1.457	3.58	2	35	3.44	6	60

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